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AVALANCHE CONTROL IN THE STARTING ZONE

(Translation of Swiss guidelines)

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SS EDITOR

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The Guidlines are valuable primarily for open structures; that is, for those structures composed of several structural members. For massive solid structures the Guidelines have to be interpreted accordingly.

The Guidelines are mandatory for all projects that are subsidized by Federal agencies. Exceptions have to be approved by the Federal Inspection of Forests and are allowed only as an experiment.

The Guidelines have been prepared by the Federal Institute for Snow and Avalanches Research (Dr. M. de Quervain and B. Salm), collaborating with Dr. R. Haefeli, Professor for Snow Mechanics and Defense Works at the Federal Institute of Technology (ETH), Zurich. The Federal Institute for Testing Materials and the Institute for Hydraulics and Soil Mechanics collaborated on some special subjects.

The authors got useful information from several State Forest Services, from Forest Rangers in charge of defense works, and from engineering companies that are interested in the development of defense structures. We thank all of these people for their help.

-- The Federal Forest Supervisor (Switzerland)

ABOUT THE COVER PHOTO: The Pallavicini Avalanche on the Arapaho Basin Ski Area, south of Loveland Pass, Colorado (May 9, 1962).

This is a typical avalanche of the central Colorado Rocky Mountain area. The bowl-shaped catchment basin extends a little above timberline and shows the very common roll of snow in the lee of the western rim. Strong winds have swept the snow off the west-facing slopes and other exposed areas, and have deposited it in the roll to the lee of the ridge.

The fracture line of the avalanche commonly forms on the steep slopes just below the roll. The moving snow masses run down the track (in this case, a slot through the timber). Small avalanches stop in the transition zone between the steep track and the more gentle creek bottom. Larger avalanches will have enough momentum to cross the stream bottom and reach the highway on the opposite slope (lower margin of photo). The zone where avalanches normally stop is called the runout-damage zone.

Structural control of this type of avalanche is possible by building supporting structures in the starting zone. Lines of snow rakes and snow bridges (see pages 10 and 11) would keep the snowpack in place and prevent avalanches from starting.

The Pallavicini Avalanche is partially controlled by protective skiing and explosives, but such control is far from complete.

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AVALANCHE CONTROL IN THE STARTING ZONE

Guidelines for the Planning and Design of Permanent Supporting Structures

Specifications Issued by the Federal Inspection of Forests (1961)
Berne, Switzerland

Lawinenverbau im Anbruchgebiet

Richtlinien für den permanenten Stützverbau

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Translated

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Rocky Mountain Forest and Range Experiment Station
with central headquarters maintained at Fort Collins
in cooperation with Colorado State University

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CONTENTS

TRANSLATOR'S REMARKS

a. As stated in the foreword of the Federal Forest Supervisor, the Guidelines are mandatory for all Swiss projects that are subsidized by Federal or State money. Since these Guidelines are intended to be a field guide, they had to be put into a brief, concise form for practical use.

b. The foreword refers to a commentary that would help understand the statements made in the Guidelines. The sponsors of this translation intend to publish a manual for the use of defense structures for avalanche control. This manual will explain how to use the Guidelines for the planning and design of permanent defense structures and should be considered a part of the Guidelines.

c. The general intention in preparing this translation of the Guidelines was to keep the English as close as possible to the original German text. Hence, the American user may find some tables and figures that have little application for him. The references made in articles 33 to 49 to Swiss standards for building materials have little value for American engineers. Therefore, the United States equivalent of the pertinent Swiss and German normals are given below:

Wood: The table in article 43 is given only for completeness. It has no value for American construction. The Swiss SIA-Norms, Nos. 163 and 164, are covered by the American National Design Specifications for Stress-Grade Lumber.[1] The general rules given in article 34 of the Guidelines are covered by articles 202-A through 202-C of the National Design Specifications.[1]

Classes I, II, and III, given in article 43, correspond to the American stress grades, "Dense construction," "Construction," and "Common structural" or "Commercial decking," respectively. The "Selected decking" for lodgepole and ponderosa pine would fit into Swiss class III. However, if these woods are used as round timber or poles, the allowable working stresses would be considerably higher than given in the National Design Specification.[1] To convert kilograms per square centimeter (kg/cm^2) into pounds per square inch (p.s.i.), multiply kg/cm^2 by 14.2. The figures in article 43 include a reduction of 30 percent and 20 percent due to the special service conditions in the avalanche defense structures, especially in the humid climate of the Swiss Alps.

Steel: Articles 35, 44, and 45 refer to steel grades defined by the DIN standards No. 17 100 (Deutsche Industrie Normen: German Industrial Normals). These quality specifications distinguish between 63 steel grades. The present Swiss Guidelines adopted the German steel normals. Article 35 suggests that the framework be made of steel of quality group 3. This is a special steel that has been treated to make it less brittle than the commercial quality. This grade of steel is recommended because of the high transportation costs and the difficulties of replacing damaged members. A lower grade of

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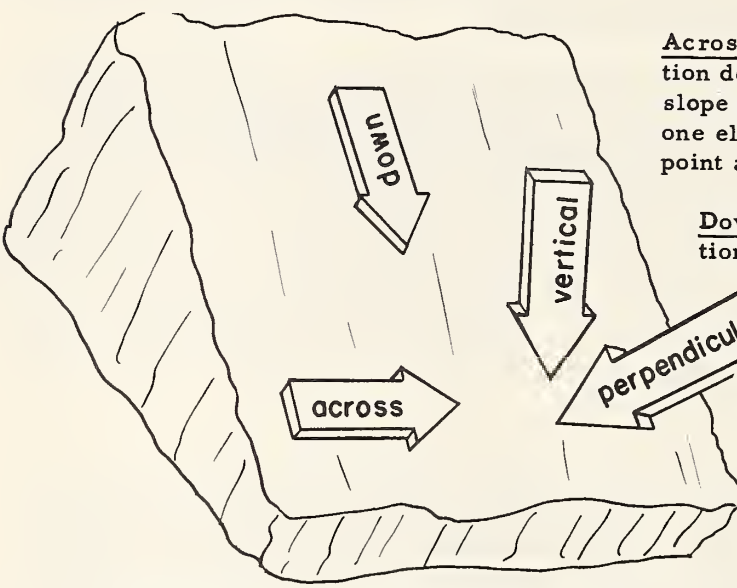
[1] National Lumber Manufacturers Association. National design specification for stress-grade lumber and its fastenings. 68 pp., illus. 1960.

steel is permitted for the grate since the crossbeams are easier to replace if damaged. Low temperatures may induce brittle behavior of the steel. Therefore, all steel used must have a high resistance to brittle fracture at low temperatures (impact testing of notch-brittle behavior).

The quality specifications of DIN No. 17 100 for steel of group 3 are covered largely by the American Standard A 7-61 T.[2] However, in article 44,1 of the Swiss Guidelines, a so-called "reduced elastic limit" is mentioned. This value, which combines the yield point with the elongation at rupture, is a characteristic that cannot be found in any American specification. The elongation at rupture is determined on a specimen whose length is five times its diameter. The unit for the stresses in the metric system is kilograms per square millimeter (kg/mm^2). To convert kg/mm^2 into p.s.i., multiply kg/mm^2 by 1,422.

<u>Light metals</u>: It is very unlikely that light metals will be used for avalanche defenses in America. Therefore, no reference is made to equivalent American standards for these metals.

d. The following terms have been used throughout this report to describe the direction of forces and motions in the three-dimensional situation encountered on a mountain slope:



<u>Across the slope</u>: The direction determined by the shortest slope distance from a point at one elevation to another nearby point at the same elevation.

<u>Down the slope</u>: The direction determined by the shortest slope distance from a higher elevation to a lower elevation.

<u>Parallel to the slope</u>: Parallel to an imaginary smooth plane lying on the surface of the ground and directed downslope (see fig. 31, vector S'_N).

<u>Perpendicular to the slope</u>: At right angles to an imaginary smooth plane lying on the surface of the ground.

<u>Vertical</u>: The alignment taken by a plumb-bob.

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[2] American Society for Testing and Materials. Tentative specifications for steel for bridges and buildings. In 1961 Book of ASTM Standards, Part I. Ferrous metals specifications. pp. 544-546. Philadelphia, Pennsylvania. 1961.

e. The German edition contained a short glossary. In order to explain to the American reader the terms used for Swiss avalanche defenses, the glossary has been enlarged considerably and follows below. The underlined terms can be found in the glossary.

GLOSSARY

ACROSS THE SLOPE: The direction determined by the shortest slope distance from a point at one elevation to another nearby point at the same elevation.

ANCHOR: Anchors are a part of the foundation. They are used when tensile forces are to be transmitted to the ground in places where good bedrock can be reached. Rock anchors are round, soft-grade steel rods of high quality. They are shaped like eyebolts or hairpins. The end that is fixed in the bedrock is upset to prevent slippage under high tensile load. Wire rope anchors have been used also.

AVALANCHE BLAST: The rush of air, produced in front of a dry snow avalanche. The most destructive form of the avalanche blast occurs when an avalanche is stopped abruptly, as in the case of an almost vertical fall into a valley floor. Such blasts may have very erratic behavior; they may level one house without damaging its neighbor.[3]

BAR: As used here, this term refers to a horizontal crossbeam. It is one member of the grate of a snow bridge (see page 10).

BARRIER: Collective name for all kinds of structures. The layman often uses this name without respect to the very different functional types. The professional would use this term only in a very general sense. When defense structures are discussed, it is best to use more precise terms such as snow bridge, snow rake, snow net, fence, etc.

BEAM: An element of the framework of snow bridges and snow rakes with the principal function of carrying a transverse load (bending stresses). The crossbeams of a snow bridge are attached to the beam (see pages 10, 11).

BEDROCK: A sound, hard, undisturbed rock in its native location, of indefinitely great extent, not broken up by harmful seams and cracks, and underlain by no material except rock. The term bedrock is used in civil engineering to characterize a very good foundation base. The applicability of snow nets, for example, depends a great deal on the ability of the ground to anchor high tension forces.

BRACING: Connecting parts of the supporting members or framework of open structures whose main purpose is to stiffen the assemblage, especially against side load.

CATCHMENT BASIN: The zone where snow accumulates to start as an avalanche; usually bowl shaped or trough shaped.

CONTINUOUS STRUCTURES: The conventional single supporting structure is about 4 meters long. In some cases it is more economical to connect single structures to form a longer, continuous structure, which often extends for

[3] Huschke, Ralph E. Glossary of Meteorology. Amer. Met. Soc., Boston, Mass. 638 pp. 1959.

hundreds of feet. The single structure in this assemblage becomes a section of the longer structure. The sections are marked by the framework, also called trestle, and are usually about 3 meters long. In contrast to the idea of using single structures to fix and stabilize the snow cover at a few points, the arrangement of continuous structures cuts the snowpack along contour lines for long distances. Synonym: Connected structures.

CONTROL SYSTEM: Structural control of avalanches is only one of several possibilities of control. Other systems are: control by explosives (artillery, hand-placed charges, pre-planted charges), control by a warning system, protective skiing. Structural control itself is divided into several classes of structures such as supporting structures, diverting structures, breaking or retarding structures, catchment structures, drift defenses, etc.

CORNICE: A snow accumulation caused by snowdrifts along a ridge or a crest. A cornice has a typical shape. Its crest is very often overhanging. The steep scarp below the face is often the starting zone for avalanches. Usually, catchment basins are garnished along the windward border by cornices.

CREEP: The extremely slow and continuous downhill movement that takes place within the snowpack between individual snow particles or snow layers. The motion that takes place at the snow-ground interface when the entire snowpack moves downslope is called glide. Creep motion can be made evident by the so-called creep profile. The movement of a line of ping-pong balls or of a column of sawdust in the snowpack is observed and the velocity distribution can be obtained for the period of observation. Creep causes large stresses in the snowpack.

CROSSBEAMS: The rigid parts of a supporting structure that are in direct contact with the snowpack. Their shape has to be adapted to the very complex play of the snow pressure forces. Crossbeams are attached to the framework. The assembly of all the crossbeams of a structure is called the grate. The area that is confined by the peripheral line of a grate represents the surface which supports the total snow load and is called the supporting plane. A distinction is made between the crossbeams of bridges and rakes. The former are called bars; the latter, rafters.

DEFENSE-WORKS AREA: The area where supporting structures are built as a defense against avalanches. It is that part of an avalanche area that is controlled by structures. The built-up area is so densely covered by structures that larger movements of the snow cover are not possible.

DOWN THE SLOPE: The direction determined by the shortest slope distance from a higher elevation to a lower elevation.

DRIFT DEFENSES: Classes of defense structures that influence the deposition pattern of drifted snow. They include wind baffles, snow fences, jet-roofs, and other types.

END-EFFECT FORCES: The forces that act on the ends of a structure as a result of plastic-viscose flow of the snow around the structure. These forces reach their maximum during the ablation period when the snowpack becomes very plastic. Synonym: Marginal forces.

FENCE: Structures with vertical functional parts. Fences may be drift defenses or supporting structures. In the first case, the function would be to influence the deposition pattern of drifted snow; in the second case, to support the snowpack.

FOOTING: The means by which the forces that develop in the framework of a structure are transmitted to the ground. The most common pressure foundation is the pedestal footing (Beam footing, support footing) in the form of a concrete block (foundation block). Tensile forces are usually transmitted by means of anchors.

FRACTURE LINE: A well-defined line where the moving snow cover breaks away from the stable snow. The observation of the fracture lines of slab avalanches is the easiest method of locating the starting zone of the avalanches.

FRAMEWORK: All structural members that transmit forces from the supporting plane to the foundation. The framework is also called a trestle. The major components of the framework are beams, supports, and purlins (see pages 10, 11).

GLIDE: The very slow downslope motion of the entire snowpack along the ground surface. Gliding is often noted on steep, grass-covered slopes during periods of high temperatures. Gliding is a very important part of the total snow pressure and depends chiefly on the angle of slope, the exposure, the ground surface, and the temperature.

GRATE: The surface or plane formed by the crossbeams of a supporting structure. The grate directly supports the snowpack uphill from the structure and transmits the snow pressure forces to the framework. Synonyms: Pressure plane, pressure surface, supporting cross section, supporting plane, bearing surface, pressure grill, and pressure grid.

GUY: A structural element used especially to secure and steady the posts of snow nets (swivel posts) and snow fences. Wire ropes are usually used for this kind of backstay.

INCLINATION OF THE SUPPORTING PLANE: The amount that the supporting plane is tilted downhill from the perpendicular to the slope. The supporting surface of older structures was more or less horizontal. That is the reason the name "snow bridge" was derived for one type of supporting structure. In later years when the modern type came into general use, the supporting surface was first built perpendicular to the slope. Although this kind of arrangement gives maximum supporting effect, it resulted in unfavorable stresses in the foundation. Therefore, the Guidelines recommend the grate be tilted about 15° downhill from the perpendicular to the slope.

LINE OF STRUCTURES: Several structures all on the same contour line of the slope. This line may be continuous (continuous arrangement) or interrupted (discontinuous arrangement).

LOCAL FOUNDATION: A footing (usually concrete) that is fabricated at the place where the structure is to be built. See also prefabriated foundation.

MESH WIDTH: The distance between adjacent wire ropes of a snow net. The mesh width of a wire rope netting corresponds to the width of opening of a grate built of crossbeams.

OPEN STRUCTURES: Assemblies of individual members such as beams and supports. They are much lighter than the older types of massive structures built of earth, stone, and masonry, but they are also more vulnerable to snow pressure forces. Synonyms: Lattice structures, framed structures.

PARALLEL TO THE SLOPE: Parallel to an imaginary, smooth plane lying on the surface of the ground and directed downslope (see fig. 31, vector S'_N).

PERMANENT STRUCTURES: Structures intended to last indefinitely. The practice of avalanche defense differentiates between permanent and temporary structures. Ideally, most structures will be replaced later by a forest. In this case, they are a temporary measure to allow the establishment of a forest. Above timberline, and when very important objects are to be protected, the structures are considered to be permanent. Permanent structures have a higher safety factor than temporary ones. They are built of durable materials such as rock, steel, and concrete. On the other hand, temporary structures are usually built of wood and are lighter, to save materials.

PERPENDICULAR TO THE SLOPE: At right angles to an imaginary, smooth plane lying on the surface of the ground.

PREFABRICATED FOUNDATION: Footings that are manufactured in a factory and intrenched at the construction site.

PRESSURE BAR: A strong bar (usually concrete) that connects the uphill (beam footing) foundation and the downhill (support footing) foundation in areas of unstable ground to prevent the uphill foundation from being pushed downhill by the component of the snow pressure parallel to the slope. Beam, support, and pressure bar form a rigid frame that gives extra support to the uphill foundation (see fig. 63,2).

PURLIN: A horizontal member of the framework of a snow rake. The upper purlin, which transmits the load from the crossbeams to the supports, may run over two or more supports. The lower purlin transmits the load directly to the ground. The latter may also be called a sill. The simplest snow rake is built of round timber. Construction with square timber is more complicated because the upper and lower purlins usually lay on beams. In both cases the purlins carry the rafters (see page 11).

RAFTER: The crossbeams of a snow rake. Rafters are inclined about 15° downhill from the perpendicular to the slope (see page 11).

ROLL: A long, wave-shaped, deep accumulation of drifted snow. Rolls have no crest and are never overhanging in contradistinction to cornices.

RUNOUT-DAMAGE ZONE: The lowest part of an avalanche area where the snow masses are stopped because of the decrease of the slope angle or a natural obstacle. In this zone some snow belonging to the avalanche cone may be found long after the surrounding snow has melted. Very often the zone is marked by debris such as earth, rocks, grass, trees, and shrubs carried by the avalanche. It is the dumpground of the avalanche. The runout zone extends as far as the hazardous influence of the avalanche may reach. This includes not only the moving snow itself, but also the avalanche blast. Synonym: Deposition zone.

SAFETY FACTOR: An empirical number by which the strength of a material is divided to obtain a conservative design stress. A safety factor is used because of uncertainties in operating conditions that may be encountered, nonuniformities in materials, simplification of design assumptions, effects of aging such as corrosion, strains introduced inadvertently during fabrication and transportation, and the seriousness of failure.

SCOOP (WIND SCOOP): A saucerlike depression in the snow near obstructions such as trees, houses, and rocks caused by the eddying action of the deflected wind. Wind baffles, a type of drift defenses, make use of the scooping effect of the wind.

SCREE: A mass of detritus, forming a precipitous, stony slope upon a mountainside; also the material composing such a slope. Scree forms a very poor base for supporting structures. The cost for a proper foundation in such material is considerably higher than on bedrock.

SETTLING OF SNOW: A plastic deformation of the snowpack under the forces of gravity. Chiefly, two internal processes are observed: The change in form of the individual particles (snow crystals) and their displacement with respect to one another. Settling is highly dependent on the temperature. Air temperatues above the freezing point accelerate the settling process. As a result of settling, the snow depth decreases and the snow density increases. A settling snowpack exerts enormous forces on obstacles.

SHAPES (OF STRUCTURAL STEEL): Collective name for rolled steel with characteristic cross sections such as angles, channels, I-beams, tees, zees, etc.

SIDE LOAD: A force acting in the across-slope direction and in the plane of the grate. It is caused by uneven terrain and varying snow depths and produces unfavorable loading of the structure. The side load is not an end effect, but acts throughout the length of a structure and depends only on the snow pressure and the span between supporting members as shown in equation 54.

SILL: The lower purlin of a simple snow rake. It rests directly on the ground.

SINGLE STRUCTURE: A structure about 2 meters in length and independent of all other such units. It is also called an element. It expresses one of the two contrasting conceptions of how to stabilize the snow in a starting zone. Dr. Haefeli (see foreword) was the leader of the idea that the snow cover can be stabilized by fixing it with elements (about 2 meters long) at a few spots. The snowpack would be strong enough to build a kind of arch between these elements and support itself. The scattered single structures in the discontinuous staggered arrangement correspond to this idea. See also the contrasting arrangement--continuous structures. Synonyms: Isolated structures, individual structures.

SLIDE (SNOW SLIDE): The downslope movement of a shallow snow layer insufficient in volume or length of travel to inflict any injury upon or to bury a person. A slide will usually come to rest very soon. Supporting structures must be strong enough to withstand the impact of slides occurring between lines of structures. Synonym: Sluff.

SLOPE DISTANCE: Distance measured on or parallel to the surface of the ground.

SNOW BRIDGE (often shortened to BRIDGE): The type of supporting structure that has horizontal crossbeams, called bars. See also inclination of the supporting plane and drawing on page 10.

SNOW DRIFT: Snow which has been moved by wind and deposited in a wind shadow; also, the moving snow itself or the event of moving snow.

SNOW NET: A type of supporting structure with the supporting plane composed of a wire rope net or, in some cases, nylon strips or wire netting. Typically, the snow net has the ability to follow, to a certain extent, the little movements of the creeping and gliding snow cover. Usually, the network is hung on swivel posts to increase its flexibility. Guys are used as backstays for the swivel posts. Another special feature of the snow net is the fact that more than half of the individual foundations are stressed by tensile forces. Therefore, rock anchorages are commonly used. If good, sound bedrock cannot be found, it is not advisable to use snow nets. In technical terminology, the prefix "snow" is dropped, and the single term "net" is used for the whole structure (see page 10).

SNOW PRESSURE: Snow pressure means either a force (tons or kilograms, t or kg) or a pressure (kilograms per square centimeter, kg/cm^2, or tons per square meter, t/m^2). The static snow pressure is the result of creep, glide, and settling of the snowpack. Supporting structures must also withstand slides and sluffs of snow that cause dynamic impact.

SNOW RAKE: A simple type of supporting structure. Often temporary wooden structures are of this type. The crossbeams of the grate are inclined about 15° downhill from the perpendicular to the slope and are called rafters (see page 11).

SPAN: The distance between the center lines of two supports. It is the width or length of a section in the case of continuous structures.

STARTING ZONE (OF AN AVALANCHE): The area where an avalanche starts. The area may change a little from storm to storm or from season to season. An important part of the basic observations for planning avalanche defenses using supporting structures is to locate these starting zones. Synonyms: Release area, rupture zone, fracture zone, catchment basin, zone of origin.

SUPPORT: An element of the framework of snow bridges and snow rakes. It is used to give support to the beam or to the purlin as a kind of post or column carrying a longitudinal load. Its position normally is not vertical but inclined toward the slope so it also functions as a backbrace.

SUPPORTING PLANE: The functional part of a supporting structure. The part of a structure that supports the snowpack uphill from the structure. In the case of snow bridges and snow rakes this plane is made up of crossbeams. In the case of snow nets, it is the network. The supporting plane is more or less perpendicular to the slope. See inclination of the supporting plane. It is not always a plane in a geometrical sense. The plane of a net, for example, is a curved surface. Bridges and rakes have rigid supporting planes. Nets have flexible supporting planes. Synonyms: Pressure surface, bearing surface.

SUPPORTING STRUCTURES: Structures intended to support, sustain, or retain the snow cover in place and to prevent it from sliding downhill. Supporting structures have to bear mainly static loading resulting from the creeping, gliding, and settling snowpack. They are built in the starting zone of the avalanche. Modern types are open structures. Snow masses already in motion cannot be stopped by supporting structures because the open-type structures are too weak to withstand large dynamic forces. However, they are designed to withstand slides and sluffs.

SWIVEL POST: Support of a snow net that swivels about its base in any direction. The joint that enables the post to swivel can be a cardan joint, a ball-and-socket joint, or a universal joint, etc. Synonym: Swinging post.

TRACK (AVALANCHE TRACK): The middle part of an avalanche area below the starting zone and above the runout-damage zone. Synonyms: Slide path, avalanche path, chute.

TRANSVERSE LOADING: The component of the snow pressure parallel to the supporting plane. This force is highly dependent upon the settling of the snowpack.

TRESTLE: The structural members used to transmit the load from the grate to the foundation. Synonym: Framework.

VERTICAL: The alignment taken by a plumb-bob.

WIDTH OF OPENING: The air gap or space between two neighboring crossbeams. Note that the width of opening is different from the center line spacing of crossbeams.

WIND BAFFLE: A panel set perpendicular to the prevailing wind direction. During snowdrifting the eddies formed by this obstacle produce a scoop around the panel. The purpose of this kind of structure is to cut the snowpack into individual portions and in this way to reduce the possibility of avalanching.

f. The metric system is used throughout this report. The following abbreviations are not common in the United States, but are used commonly in Europe. They have been retained in the translation because several of the equations in the original Guide have been photocopied for use in the translated article.

m' -- running meters

t -- metric tons; 1 ton equals 1,000 kilograms or 2,200 pounds

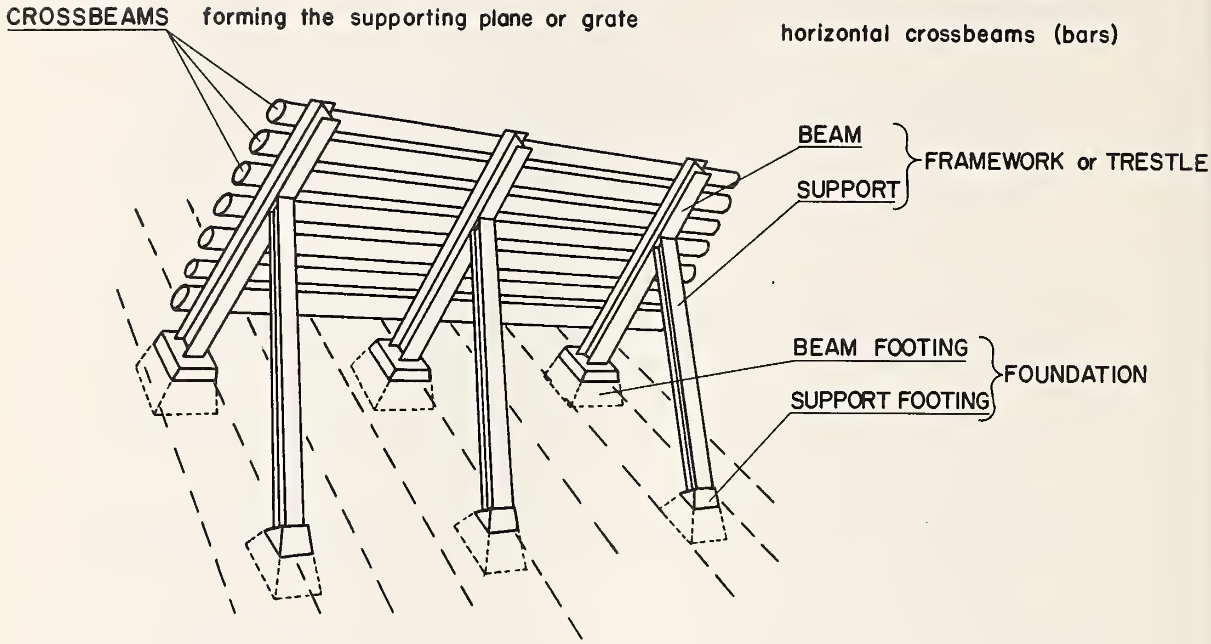
tg -- the tangent of an angle; 'tan' is the English abbreviation

It is hoped that the explanations and definitions given will help the reader to a better use of the translated material.

-- Hans Frutiger, Translator

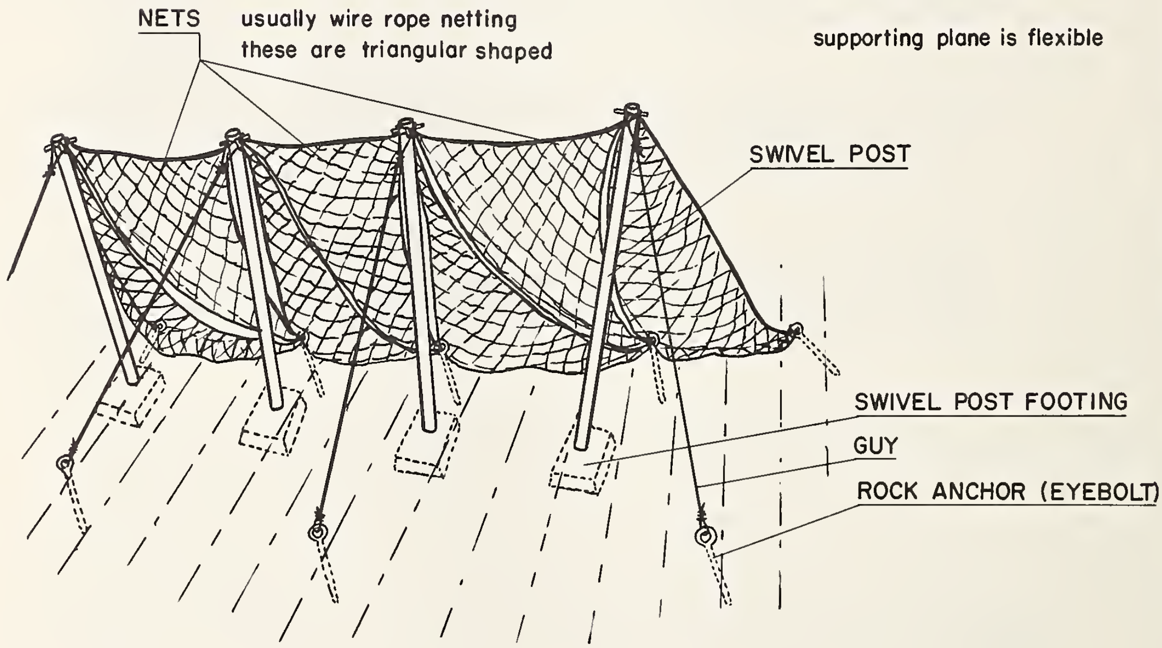
SNOW BRIDGE

horizontal crossbeams (bars)



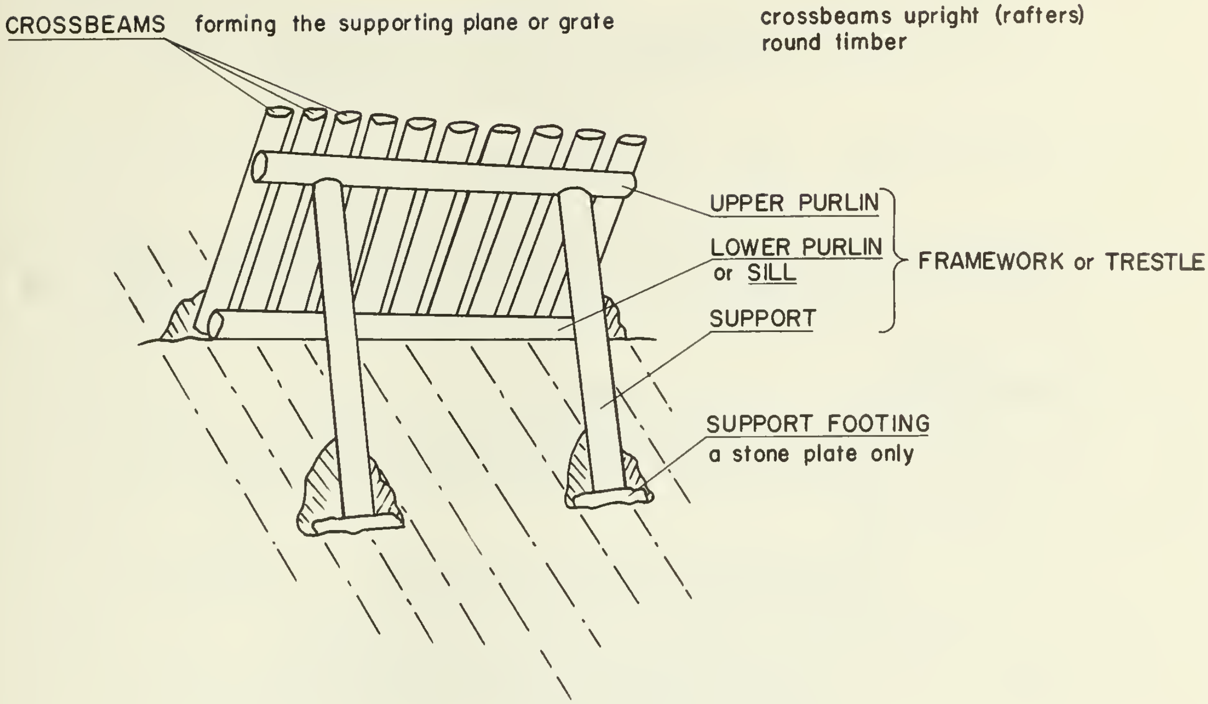
SNOW NET

supporting plane is flexible



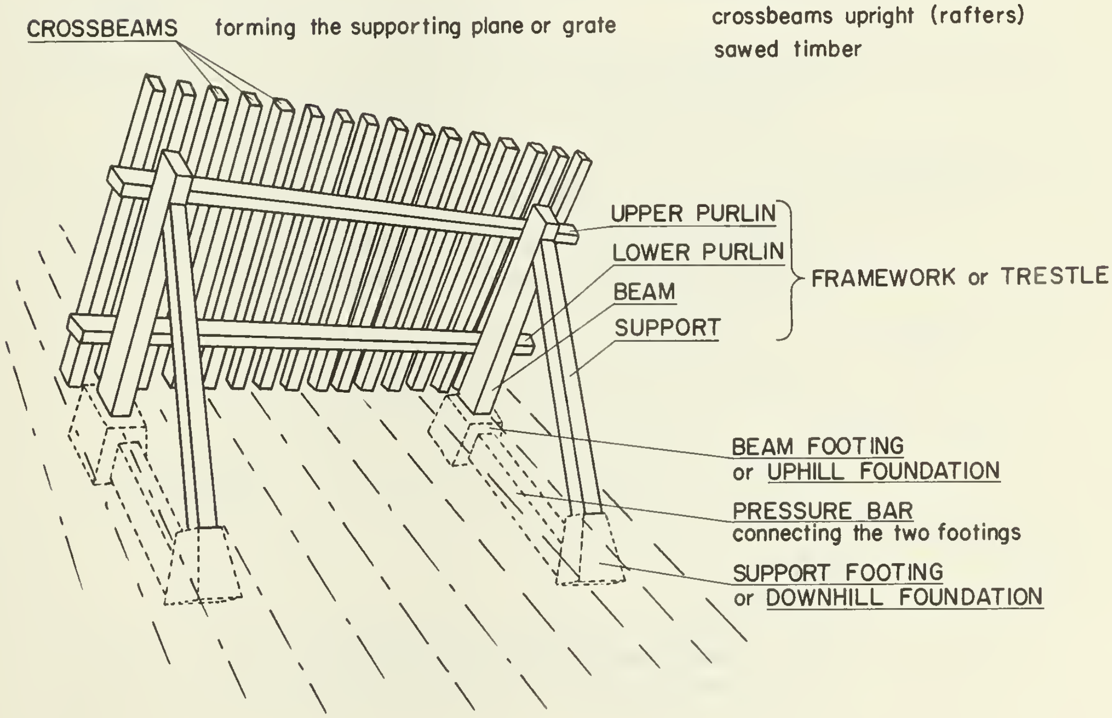
SNOW RAKE

crossbeams upright (rafters)
round timber



SNOW RAKE

crossbeams upright (rafters)
sawed timber



TRANSLATION

OF

AVALANCHE CONTROL IN THE STARTING ZONE

by

Hans Frutiger

- - - -

SYMBOLS USED IN THE SPECIAL FIELD OF AVALANCHE DEFENSES

(More detailed explanation of the symbol is given in the underlined article)

Symbol	Unit of measure	Meaning	Article
A	m	Interval: The space between two structures measured across the slope.	23,1./23,2./24,2./24,3./52,5.
a	–	Ratio (relative number) to determine ε (this number depends upon the kind of snow).	28,1./52,3./55,2./57,3.
B_K	m	Slant height of a grate or of a net (average height of the supporting plane measured parallel to the plane.	19,1./54,2./55,2./55,3./57,3.
b	m	Loading width of bars and rafters in the supporting plane.	55,2./57,1./57,2./57,3./57,4./58,1/58,2./58,5.
D	m	Extreme thickness of the snow cover measured perpendicular to the slope at a particular spot.	15/52,4./52,5.
D_K	m	Effective height of the grate or the net (average distance between upper borders of the supporting plane and the ground measured the same way as the thickness of the snow cover).	19,2./24,4./24,5./52,5./55,2./57,3.
D_S	m	General thickness of the snow cover measured perpendicular to the slope.	15/29/31,4.
f_C	–	Altitude factor: Accounts for the variation of snow density and snow creep with the altitude.	25,1./25,2./25,6./52,2./59,1./62,2.
f_L	–	Distance factor: Used to calculate the distance L.	21/22,1.
f_R	–	End-effect factor: Used to calculate the end-effect forces.	25,1./52,5./53,4.

Symbol	Unit of measure	Meaning	Article
f_S	–	Reduction factor for the component of the snow pressure parallel to the slope when the supporting plane is flexible.	59,1.
G'	t/m'	Weight of that snow prism which is confined by the supporting plane and a plane perpendicular to the slope at the foot of the supporting plane.	29/52,4./59,4.
G'_N, G'_Q	t/m'	Components of G' parallel and perpendicular to the slope, respectively.	29/31,2./31,3.
H	m	Extreme vertical snow depth (peak of the maximum snow depths during a long period at a particular spot) usually estimated from H_m values.	14,3./16/18/ 22,1./25,2./ 25,3./52,1./ 52,2./52,4./ 52,6./53,2./ 53,3./59,1./ 62,2.
$\overline{H}$	m	Average extreme vertical snow depth: Average of the extreme snow depths over a given area at the moment of the longtime maximum of snow depth.	14,4./16.
H_K	m	Vertical height of a structure.	7,1./17/18/21/57/ 10/58,7./59,8.
H_m	m	Maximum vertical snow depth for a winter season at a definite spot.	14,1./14,3./16.
$\overline{H}_m$	m	Average maximum vertical snow depth: Average of H_m over a definite area.	14,2./14,3./16.
H_S	m	General snow depth, measured vertically.	4,2./13/15/25,1./ 27,1./31,4.
h	m	Snow depth associated with the second type of loading.	53,2./53,3.
K	—	Creep factor: A function of snow density and the angle of the slope.	25,1./25,4./25,6./ 27,1./52,1.
L	m	Slope distance between the structures (the distance measured along the ground surface).	21/22,2./23,1./ 23,3.
l	m	Length of a structure measured across the slope.	24,1./24,2./24,3./ 24,4./57,11./59,9.
l_W	m	Effective length of a structure: Length of the structure plus the length of the lateral zones of influence measured across the slope.	24,2.

Symbol	Unit of measure	Meaning	Article
Δl	m	Length of application of the end-effect forces measured across the slope.	30, 1. /31, 3. /31, 5. / 52, 5. /53, 4. /55, 2. / 55, 3.
l_o	m	Horizontal distance between two neighboring points of support for a bar, a purlin, or a net (width of a section or span).	54, 2.
N	–	Glide factor: A function of the roughness of the ground surface and the aspect of the site.	21/25, 1. /25, 2. / 25, 5. /27, 1. /28, 1. / 52, 2. /52, 3. /52, 5. / 59, 1. /62, 2.
P'	t/m'	Component of R' perpendicular to the supporting plane.	55, 2.
p_B	t/m'	Loading of a bar or rafter perpendicular to the supporting plane (grate).	55, 2. /57, 4. /57, 6. / 58, 5.
p_H	t/m^2	Specific snow pressure perpendicular to the supporting plane in the case of the first type of loading.	
p_h	t/m^2	Specific snow pressure perpendicular to the supporting plane in the case of the second type of loading.	55, 2. /57, 4. /58, 5. / 61.
Q'	t/m'	Component of R' parallel to the supporting plane (grate).	57, 3.
q_B	t/m^2	Load on a bar or rafter parallel to the supporting plane (grate).	57, 3. /57, 4. /57, 5. / 57, 6. /58, 5.
q_H	t/m^2	Specific snow pressure parallel to the supporting plane (grate) in the case of the first type of loading.	
q_h	t/m^2	Specific snow pressure parallel to the supporting plane (grate), in the case of the second type of loading.	57, 3.
q_S	t/m'	Transverse force working upon the swivel posts perpendicular to the axis of the posts.	62, 2.
R'	t/m'	Resultant force created by all the individual snow pressures.	31/53, 3. /55, 2. /57, 3. / 58, 5. /59, 6.
S'_N	t/m'	Snow pressure parallel to the slope (creep and glide pressure).	26/27, 1. /27, 2. / 28, 1. /31, 2. /31, 3. / 52, 2. /52, 3. /52, 5. / 54, 2. /59, 1.
S'_Q	t/m'	Component of snow pressure perpendicular to the slope (creep pressure).	26/28, 1. /28, 2. / 31, 2. /52, 3. /59, 3.

Symbol	Unit of measure	Meaning	Article
S'_R	t/m'	Additional snow pressure parallel to the slope and working on the lateral edges of the supporting plane (end-effect force).	30,1./31,3./ 52,5./55,4.
S_S	t	Side load on a structure (acts in the across-slope direction and in the plane of the grate).	32/54,2.
s_B	t/m²	Breaking shear stress in the undisturbed soil along the surface of a foundation (tensile stresses).	66,3./67,2.
s_{zul}	t/m²	Permissible shear stresses in the undisturbed soil along the surface of a foundation (tensile stresses).	66,3.
s^*_{zul}	t/m²	Permissible shear stresses in the refilled soil along the surface of the foundation (tensile stresses).	67,2.
T	t	Resulting single force that works upon the upper foundation.	63,1./66,1./66,2./ 66,3./67,2./68,1.
t	m	Foundation depth (measured vertically).	66,3./67,2.
U	t	Resulting single force that works upon the lower foundation.	63,1.
w	m	Width of opening between members of the grate.	57,8./58,6./ 59,7.
α	°	Angle between the direction of the force and the direction of the slope (foundations).	64,3./64,4.
γ_H	t/m³	Average snow density corresponding to the snow depth H (first type of loading).	25,2./52,1./ 53,2.
γ_h	t/m³	Average snow density corresponding to the snow depth h (second type of loading).	53,1./53,2.
γ_S	t/m³	Average snow density.	25,1./25,6./27,1./ 29/59,4.
ε	°	Angle between the resultant of forces S'_N and S'_Q (vectorial addition) and the direction parallel to the slope.	28,1./52,3.
ε_R	°	Angle between the resultant of all snow pressure forces and the direction parallel to the slope.	31,5./55,2./ 57,3.
η	—	Efficiency of a structure in regard to snow pressure.	30,2./62,2.

Symbol	Unit of measure	Meaning	Article
ϱ	^{0}	Angle between the supporting plane and a plane perpendicular to the slope at the foot of the supporting plane (tilt of the grate).	29/33/51/52,4./ 55,2./57,3.
σ_α	t/m²	Soil pressure in the direction of the applied load.	64,3./66,1.
σ_0	t/m²	Soil pressure in the direction of the slope.	64,3.
φ	^{0}	Angle of friction when the snow cover glides on the earth surface.	21
φ_E	^{0}	Angle of friction in transmitting pressures (foundations).	66,3./67,2.
ψ	^{0}	Angle of the slope.	3/7,2./15/21/ 22,1./22,2./ 25,1./25,4./ 25,5./27,1./ 28,1./52,1./ 52,3./52,4.

I. SITE CONDITIONS AND GENERAL ARRANGEMENT OF SUPPORTING STRUCTURES ON SLOPES

A. FACTORS THAT CAUSE AVALANCHING

a) SLAB AVALANCHES

ART. 1 Two types of motion take place in the snow cover lying upon a slope. One is between individual snow particles or layers, and is called creep motion. The other, called gliding, takes place at the ground-snow interface when the entire pack moves downslope (Fig. 1).

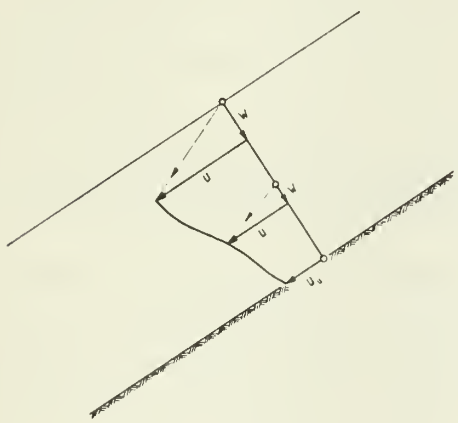


Fig. 1.

Velocity profile of the snow cover.

$\mathfrak{v}$	(u, v, w) resultant vector of velocity
u	velocity component parallel to the slope
u_u	glide velocity
$u-u_u$	creep velocity parallel to slope
w	creep velocity perpendicular to slope

On a plane slope, with uniform ground roughness, and uniform snow cover conditions, the velocity profile of figure 1 will be the same from place to place. In this case the weight of the snow cover will be transmitted directly to the ground as a normal pressure and as a shearing stress.

This so-called neutral zone is characterized by the absence of tensile or compressive stresses that vary from place to place along the slope. Slab avalanches can occur in this zone only if the shear strength of the snow cover near the ground is exceeded (ground avalanche) or if an extremely weak layer in the snow cover is overstressed (surface avalanche). The following may act as external triggers: Overloading by snowmasses, skiers, wind pressure, etc.

The following factors cause local variations in the creeping and gliding motions:

---variable slope
---variable snow depth
---variable roughness of the ground
---variable qualities of the snow cover (plasticity, friction, particularly a wet interface between the snow and the ground)

All of these produce zones of increased tensile and compressive stresses parallel to the slope.

The tensile zones are potential rupture zones for slab avalanches. They exist primarily in convex transition zones (where the slope steepens downward), in areas where deep snow accumulates, in the transition zone from rocky ground to the talus of a debris cone, and where the snow depth increases from the top to the bottom of a slope.

b) LOOSE SNOW AVALANCHES

ART. 2 Loose snow avalanches take place in light, fluffy snow in which there are very few, if any, internal stresses. Normally, only a small impulse such as a falling stone or a snow clod is required to trigger a loose snow avalanche. The motion caused by the initial disturbance is enough to put more snow into motion. The fracture line increases in length and becomes pear-shaped.

c) RELATION OF SLOPE ANGLE TO THE FORMATION OF AVALANCHES

ART. 3 Avalanches do not originate on slopes less than 17° (30%) and only rarely on slopes flatter than 30° (57%).

When slopes exceed 45° (100%), loose snow avalanches are common. These cause a frequent unloading of the slope which reduces the stresses within the snow cover and minimizes the probability of slab avalanches.

Slopes to be controlled by structures range, in general, from 32° to 50° (62% to 120%).

In exceptional cases flatter or steeper parts of a slope may be controlled; for example, flat shoulders above steep slopes.

B. THE PURPOSE AND THE EFFECT OF SUPPORTING STRUCTURES

ART. 4 1. The purpose of supporting structures is to prevent slab avalanches from starting in the area under protection and to stop loose snowslides within a short distance. Often the start of a loose snow avalanche cannot be prevented.[4] Avalanches traveling at full speed have too much power to be stopped or controlled by supporting structures.

2. Supporting structures reach from the bottom to the top of the snowpack, and as their name implies, they support the snow cover.

These structures, which are erected more or less perpendicular to the slope and are well anchored in the ground, act as dams against creeping and gliding motions. A back-pressure zone extends uphill from the structure for a slope distance of at least three times the vertically measured snow height. This means that motions are diminished downslope toward the obstacle. Within the back-pressure zone, additional pressure stresses are produced in the snowpack. These pressure stresses are parallel to the slope and depend primarily upon gliding. The supporting structure is able to withstand all such stresses. In this way the shear and tensile stresses that produced slab avalanches before the structures were built are reduced in the back-pressure zone of the structure.

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[4] Translator's note: Since recent experience has shown that even slab avalanches can start between lines of supporting structures, these structures must be strong enough to withstand this dynamic loading.

C. REFERENCE TO OTHER DEFENSE SYSTEMS

a) DRIFT DEFENSES

ART. 5 1. Light structures, such as fences and panels, which influence the wind and deposition of snow with the goal of

---reducing the number of slab avalanches
or
---preventing the formation of cornices.

b) DIVERSION STRUCTURES

2. Massive structures such as dams, stone walls, and galleries intended to divert or to split a moving avalanche. These structures must be designed to withstand the large forces produced by moving snow masses.

c) RETARDING AND CATCHMENT STRUCTURES

3. Structures such as mounds and breakers intended to shorten the avalanche path by reducing the momentum of the moving snow, or catching walls or dams intended to retain the moving snow. These structures must also be designed to withstand large forces.

4. These defense systems may be used to supplement supporting structures.

D. GENERAL KINDS OF STRESSES ACTING UPON SUPPORTING STRUCTURES

ART. 6 Defense structures are stressed not only by the static snow pressure (see Art. 4, 2) but also by dynamic forces caused by loose snow sluffs. Static snow pressure forms the basis for the design of the structures, while the possible dynamic forces determine the layout or arrangement of the structures.

E. EXTENT AND ARRANGEMENT OF SUPPORTING STRUCTURES

The arrangement and the dimensions of supporting structures have to conform to the purpose (Art. 4) and the kinds of stresses (Art. 6).

a) LOCATION OF THE STRUCTURES IN RELATION TO THE FRACTURE LINES

ART. 7 1. The primary location for supporting structures is below the highest fracture lines that were observed or are expected (Art. 1, Art. 4). The fracture lines must lie within the back-pressure zone of the structures. According to Art. 4, 2, this will be the case if the structures in question are erected not more than 2-3 H_K below the fracture lines. (H_K is the vertical height of the structure.) After the erection of the first line of structures, new and secondary lines of fracture will usually appear farther down the slope. Therefore, structures will be needed in what was formerly the neutral zone.

2. The area where structures must be built extends downhill until

---either the angle of the slope is definitely less than 32°
or
---it is expected that avalanches breaking off farther downhill will be too small to be dangerous.

b) ARRANGEMENT OF THE STRUCTURES IN RELATION TO THE DIRECTION OF THE SNOW PRESSURE

ART. 8 As seen in a plan view, the long axis of the structures must be placed as nearly as possible at right angles to the assumed direction of the snow pressure. This is most important in narrow depressions in the slope.

c) SPECIAL PRECAUTIONS CONCERNING THE TOPMOST LINE OF STRUCTURES

ART. 9 1. If the slope to be protected is bordered by a ridge where cornices ordinarily build up, the topmost structures must be placed as near as possible to the foot of the cornices, but should not be close enough to be buried by a developing cornice. These structures must be built particularly strong to allow for the heavier snow load and because parts of the cornice may fall upon them. In many cases, the formation of cornices may be reduced by drift structures which may be constructed before the installation of supporting structures.

2. If the slope to be protected is very steep or has cliffs in the upper portions, the topmost structures have to be as strong as possible and must be protected against rockfall. Suitable protection is given by a wooden or steel grate, a layer of turf, or nets.

In some cases diversion or catchment structures may be built to prevent snow, ice, and rocks falling from the cliffs from damaging the structures.

d) LATERAL EXTENT OF SUPPORTING STRUCTURES

ART. 10 1. The top of the defense-works area has to be as close as possible to the upper part of the fracture zone. The layout should be wide enough to protect an entire natural terrain unit. To do this it should extend laterally to natural terrain borders such as crests, terrain ripples, etc. (Fig. 10, 1).

2. If this is impossible because of terrain configuration or economic difficulties, each line of structures must be shorter than the one immediately above it. By stepping back the open or exposed ends of successive lines of structure, avalanches starting near the upper line of structures cannot damage structures on the exposed flanks of lower lines of structures (Fig. 10, 2).

To prevent a slab avalanche that starts in an adjoining area from spreading into the defense-works area a protecting wall or a drift structure may be useful (Fig. 10, 2).

e) CONTINUOUS AND DISCONTINUOUS ARRANGEMENT OF STRUCTURES

ART. 11 1. The continuous arrangement consists of long, horizontal lines of structures that extend over the entire defense-works area. These lines of

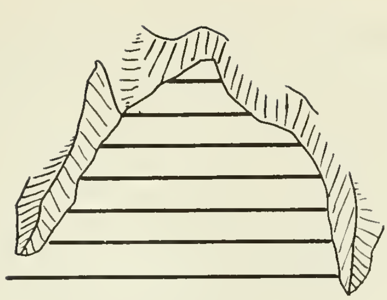


Fig. 10, 1.

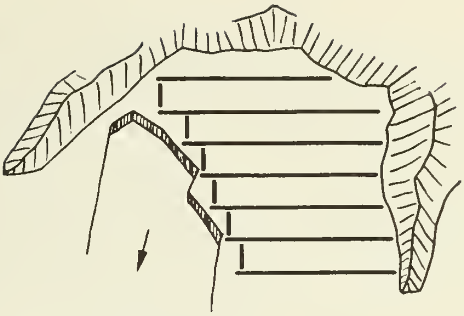


Fig. 10, 2.

Complete (Fig. 10, 1) and partial control (Fig. 10, 2) of a natural terrain unit. Staggering back and delineation of an unprotected flank of a defense-works area.

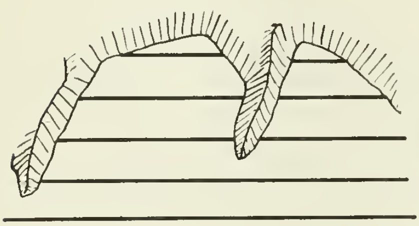


Fig. 11, 1. Continuous.

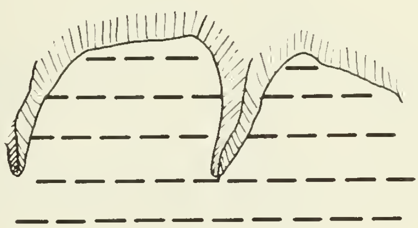


Fig. 11, 2. Interrupted.

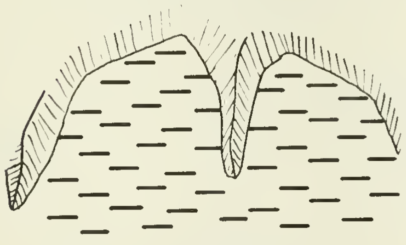


Fig. 11, 3. Staggered.

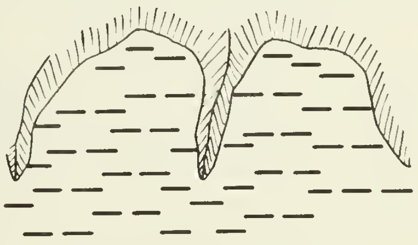


Fig. 11, 4. Combination of discontinuous arrangements.

Continuous and discontinuous arrangement of structures.

structures are interrupted only in spots where fractures of the snow cover cannot occur (Fig. 11, 1).

2. Discontinuous arrangements may be either an interrupted line of structures or a staggered arrangement of individual structures. The latter includes the echelon arrangement.

3. The interrupted arrangement of structures can be derived from the continuous arrangement by leaving gaps in the horizontal work ranges (Fig. 11, 2).

4. The staggered arrangement of structures consists of single structures in echelon (Fig. 11, 3). Another type of staggered arrangement has no prescribed pattern (Fig. 11, 4).

5. The following table gives the advantages and disadvantages of the three primary arrangements:

Arrangement	Advantages	Disadvantages
Continuous (Art. 11, 1)	---continuous obstacle for loose snow slides. ---tension stresses in the snow cover seldom develop. ---end forces are reduced to the ends of the work ranges (total snow pressure stresses are minimized).	---limited applicability on irregular terrain or broken ground and when the snow depths change locally. ---large continuous areas of snow still exist where tensile and shear stresses can develop. ---damages may be propagated laterally.
Interrupted (Art. 11, 3)	---a good fit to terrain configuration and to local changes in snow depths is possible. ---damage from moving snow will be localized to single sections. ---cheaper than the continuous arrangement in certain cases.	---loose snow can flow through the intervals. ---each individual structure is subject to end forces.
Echelon and staggered (Art. 11, 4)	---most adaptable to the terrain configuration in all directions. ---all permanent tensile and shear stress zones are divided. ---gliding of snow cover between the works is reduced.	---stressing by end force corresponds to an isolated structure. ---cost per unit length of structure is higher than the continuous and the interrupted arrangements.

6. Optimum effectiveness with minimum costs is often gained with a combination of the different arrangements. In an area where the terrain and the depths of the snow cover vary greatly, the staggered arrangement would be best; on a uniform slope, the continuous arrangement of structures would be more advantageous. In case of doubt, an economic analysis will show the best arrangement.

f) RIGID AND FLEXIBLE SUPPORTING STRUCTURES

ART. 12 1. If the supporting plane of a structure undergoes only slight elastic deformation due to the creeping and gliding of the snow cover, then this supporting plane and structure are said to be rigid.

2. If the supporting plane of a structure can follow the movement of the snow to a certain extent, then this supporting plane and structure are said to be flexible (for example, snow nets).

F. SNOW DEPTH AND HEIGHT OF STRUCTURE

ART. 13 The depth of snow measured vertically, H_S , is characteristic for the snowpack of a given area. If the snow falls perpendicularly and regularly (no wind), the vertical snow depth is independent of the angle of the slope.

a) DEFINITIONS OF SNOW DEPTHS

ART. 14 1. Maximum snow depth (H_m): The maximum snow depth for a winter season at a definite spot (for example, at the site of a structure).

2. Average maximum snow depth ($\bar{H}_m$): Average snow depth in a given area (for example, in a defense-works area) at the moment of the general maximum snow depths in a winter season.

3. Extreme snow depth (H): The greatest snow depth to be expected over a longtime interval (about 30 years) measured at a certain spot (for example, at the site of a structure).

4. Average extreme snow depth ($\bar{H}$): The average snow depth in a given area (for example, in a defense-works area) at the moment of the extreme snow depth (may occur only once in 30 years).

b) DEFINITION OF THE THICKNESS OF THE SNOW COVER

ART. 15 We call the snow depth measured perpendicular to the slope the thickness of snow, and designate it D (D_S, D_m, D , etc.)

$$D_S = H_S \cdot \cos \psi \qquad (15)$$

c) DETERMINATION OF THE EXTREME SNOW DEPTH

ART. 16 The extreme snow depth at the sites where structures are to be built (Art. 18) are basic for planning avalanche defenses. Since it can be observed directly in only a few cases, the extreme snow depth is often estimated by observing the snow distribution through a few winters. Valuable observations can often be made during the snowmelt period.

The estimation of extreme snow depth will be possible provided that:

---distribution of snow depths over the entire defense-works area is the same from year to year, that is, the deepest snow is in the same place each year.

---maximum snow depths, H_m , at the structure sites have been measured through one or more winters.

---average maximum snow depth, $\overline{H}_m$, in the defense-works area had been calculated for the same period of observation. An equivalent value may be gained from a snow stake that is representative of the average snow accumulation.

---average extreme snow depth, $\overline{H}$, of the defense-works area is known or can be calculated from long-term observations taken at stations in the neighborhood, after such observations are adjusted on the basis of the relationship between precipitation and altitude.

In such cases, the extreme snow depth, H , at a structure site is:

$$\boxed{H = H_m \cdot \frac{\overline{H}}{\overline{H}_m}} \quad (16)$$

(H_m and $\overline{H}_m$ must refer to the same period of observation)

d) DEFINITION OF THE VERTICAL HEIGHT OF A STRUCTURE

ART. 17 The vertical height of a structure, H_K , is defined as the average vertical distance between the upper border of the supporting plane and the ground.

The definitions for the particular types of structures will be found in Section III (snow bridges, Art. 57,10; snow rakes, Art. 58,6; and snow nets, Art. 59, 8).

e) REQUIREMENTS FOR THE VERTICAL HEIGHT OF A STRUCTURE

ART. 18 The vertical height, H_K , of a structure must correspond to the expected extreme snow depth at the location of the structure.

$$\boxed{H_K \geqslant H} \quad (18)$$

This fundamental requisite must be recognized for effective protection against avalanches during catastrophic situations and for the design of the structures.

Where $H_K > H$, H_K will determine the dimensions of the structure.

It should be noted that the structures, depending on their features and on the wind conditions, may themselves considerably influence snow depositions.

f) DEFINITION OF THE SLANT HEIGHT OF A STRUCTURE

ART. 19 1. The slant height of a structure, B_K , is defined as the average height of the supporting plane measured parallel to the supporting surface of the structure. The lower limit is formed by the ground (Fig. 19).

2. The effective height of a structure, D_K, is defined as the average distance between the upper border of the supporting plane and the ground measured perpendicular to the slope. This is analagous to the thickness of the snow (Fig. 19).

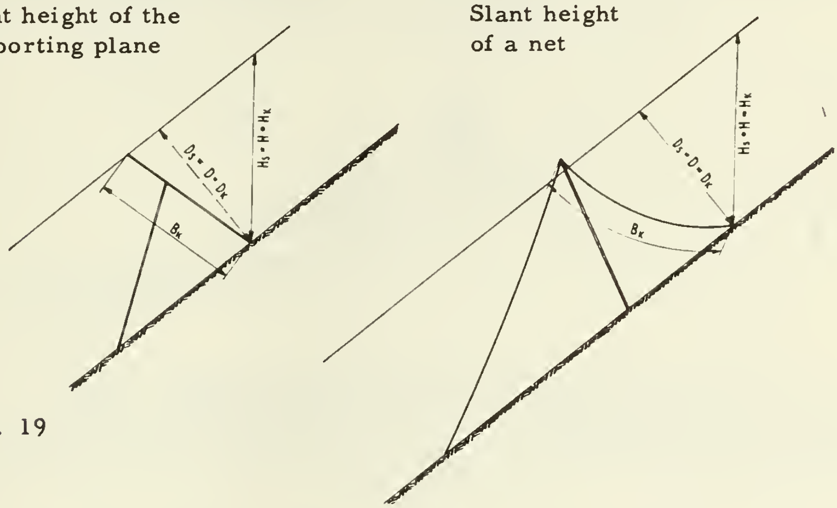


Fig. 19

G. SLOPE DISTANCE BETWEEN LINES OF STRUCTURES
(measured down the slope)

ART. 20 The slope distance between individual structures or between lines of structures is dependent upon the pressure of the snow, the depth of the snow, and the vertical height of the structures. As snow depths increase, vertical height and strength of the structures must be increased proportionately. Taller, stronger structures allow a wider spacing of the lines of structures if we assume a constant safety factor for the dynamic stresses.

a) DISTANCE FORMULA

ART. 21 The slope distance between structures and lines of structures is

$$\boxed{L = f_L \cdot H_K} \qquad (21, 1.)$$

The distance factor f_L is

$$f_L = \frac{2 \ \mathrm{tg}\,\psi}{\mathrm{tg}\,\psi - \mathrm{tg}\,\varphi} \qquad (21, 2.)$$

where φ is the angle of friction between snow and ground. Figure 21 shows f_L as the function of the inclination of the slope ψ for three values of the tangent of the friction angle φ.

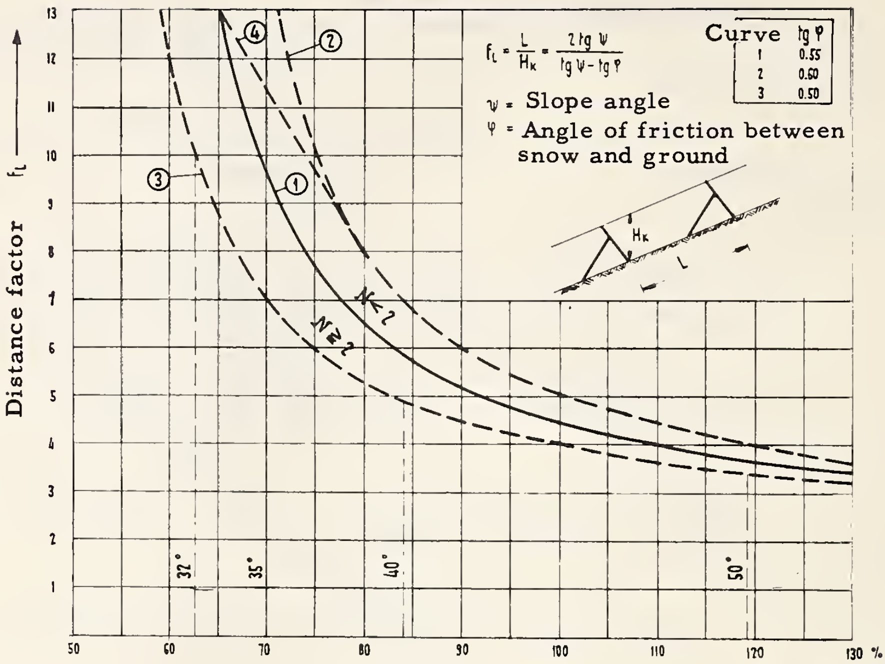


Fig. 21 $tg\,\psi$ = Slope angle in %

---Curve 1 ($tg\,\varphi = 0.55$) is the normal curve.
---If the ground is smooth (gliding factor $N \geqslant 2$, according to Art. 25, 5), the area between curve 1 and 3 is used.
---If the ground is very rough ($N < 2$), the area between curves 1 and 2 is to be used.

b) ADDITIONAL SPECIFICATION FOR THE CALCULATION OF THE SLOPE DISTANCES BETWEEN STRUCTURES AND LINES OF STRUCTURES

ART. 22 1. If the angle of slope is moderate (under 35° or 70%), and the snow is deep, the resulting theoretical distances are very large in relation to the effective back-pressure zone. Since in such cases the possibilities of damage to the structures from dynamic snow effects are not known, an upper limit should be placed on the solution for the distance factor f_L. In figure 21, this upper limit is $f_L = 13$ and the straight line 4.

2. If the slope angle changes between the structures or lines of structures, the angle ψ of the straight line between the base of the two corresponding structures should be used for the calculation of L.

H. INTERVAL BETWEEN STRUCTURES
(measured across the slope)

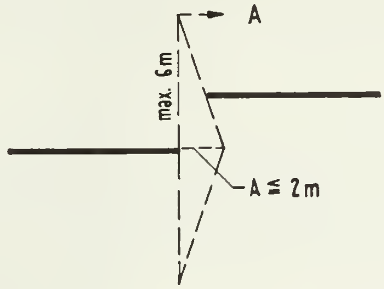
ART. 23 Intervals between adjacent structures lying on the same contour line are determined according to the following considerations:

1. In the case of the interrupted arrangement, the interval A must be limited to 2m: $A \leqslant 2\,m$. In cases where terrain features prevent avalanches

from starting, A may be larger than 2m. At a distance no greater than L above each interval A there must be a structure. Of course, this does not apply for the topmost line of structures.

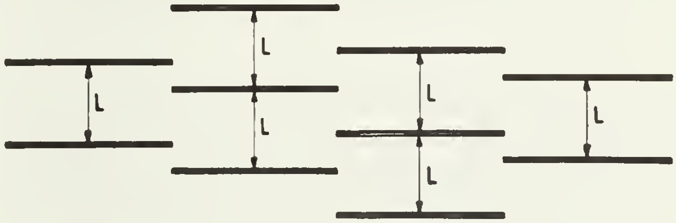
2. If adjoining structures are displaced down the slope, the projection of the gap down the slope has to be reduced in proportion to the displacement (at 6 meters the gap disappears)(fig. 23, 1).

Fig. 23, 1



3. For staggered structures, the interval between structures is optional, but intervals of more than 2m must be partially protected according to Art. 23,2, or must be entirely protected by structures that are spaced the normal distance L.

Fig. 23,2



I. THE LENGTH OF STRUCTURES

ART. 24 1. The length l of a structure is the average actual length of the supporting plane measured across the slope (snow bridges, Art. 57, 11; snow nets, Art. 59, 9).

2. The effective length l_W of a structure is composed of the length of structure, l , and the lengths of the lateral zones of influence.

Example: In the case of interrupted structures

$$l_W = l + 2\frac{A}{2}$$

3. In the case of interrupted structures, the minimum length l of the single structure will be 2A (Fig. 24, 1).

4. In the case of staggered structures, the minimum length l of the single structure will be 2 D_K (D_K is the effective height of a grate or a net) (Fig. 24, 2).

5. In a combination of interrupted and staggered arrangements, the total length of the structure sections on the same level, including the intervals, has to be at least 2 D_K . (Fig. 24, 3).

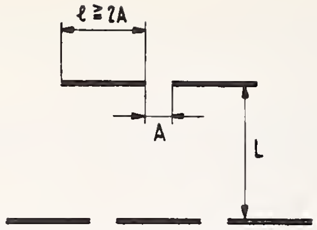


Figure 24, 1. Discontinuous.

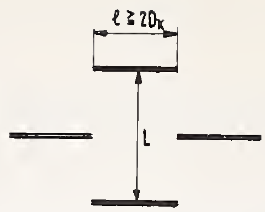


Figure 24, 2. Staggered.

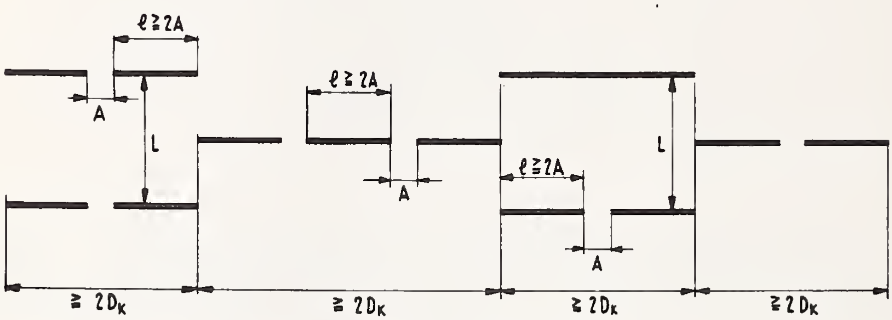


Figure 24, 3. Combined.

K. FACTORS INFLUENCING THE SNOW PRESSURE

ART. 25 1. The snow pressure acting on a supporting structure depends upon the factors listed below. Except for the average density of the snow and for the creep factor, all of these factors must be determined in the field for each project and eventually for each work location.

- γ_S average density of the snow
- H_S snow depth at the structure site
- K creep factor; varies with the density of the snow and the angle of the slope
- N glide factor; a function of the vegetation, roughness of the ground surface, and the aspect of the site
- f_C altitude factor; takes into account the relationship between the density of the snow cover and altitude
- f_R end-effect factor; a function of the interval between individual structures or lines of structures and the glide factor.

The calculation of the snow pressure based on the above factors is given in Sections II and III.

a) SNOW DENSITY

2. The average density of the snowpack at the time of the extreme snow depth is assumed to be

$$\gamma_H = 270 \text{ kg/m}^3$$

This value applies to conditions in the Swiss Alps for an altitude of 1, 500 m above sea level and a WNW-N-ENE aspect. The altitude factor, f_C , (Art. 25, 6) and the glide factor, N , (Art. 25, 5) take into account the change in this basic value with altitude and aspect. The specifications for designing structures when the snow density has increased due to settlement is covered in Art. 53.

b) SNOW DEPTHS AT THE WORK LOCATION

3. The factor which serves as the original datum for the calculation of the snow pressure is the extreme snow depth, H, at the work location as determined in Art. 16.

c) CREEP FACTOR

4. The relation between the creep factor, the snow density, and the angle of slope is shown in Section II (Art. 27, 1). For practical purposes the creep factor is independent of the slope angle for slopes between 35° and 45° (let $\sin 2\psi = 1$).

d) GLIDE CONDITIONS AND THE GLIDE FACTOR

5. The glide factor, N, which indicates the increase in the snow pressure caused by movement at the ground-snow interface (see Art. 1) depends on the roughness of the ground and the aspect of the slope. The glide factor, N, is graded into eight values based on four classes of ground and two classes of aspect (see table, p. 30).

If the roughness of the ground surface falls between the classes indicated in the table, intermediate values of N may be interpolated. When the steepness of the slope is more than 45°, N must be chosen more carefully; if the angle of slope is less than 35°, the evaluation of N is less critical.

If N is high, the surface of the ground should be roughened by artificial measures--terraces, poles, etc., because this is usually cheaper than increasing the strength of the structure.

e) ALTITUDE FACTOR

6. The altitude factor, f_c, is not a basic constituent of the snow pressure formula, but is taken into account in the snow density. It expresses the general increase in snow density with altitude and the increase in the creep factor associated with this higher density. In the Swiss Alps snow pressure increases 2% per 100 m for altitudes between 1,500 and 3,000 meters above sea level.

Altitude above sea level (m)	Altitude factor, f_c	Altitude above sea level (m)	Altitude factor, f_c
1,500	1.00	2,000	1.10
1,600	1.02	2,100	1.12
1,700	1.04	2,200	1.14
1,800	1.06	2,300	1.16
1,900	1.08		

For altitudes less than 1,500 m above sea level, f_c is 1.00, and for altitudes more than 3,000 m above sea level, f_c is 1.30.

L. GEOLOGY AND SOIL CONDITIONS

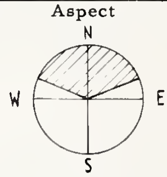
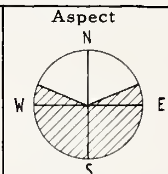
7. A thorough examination of geology and soil conditions is an important step in planning avalanche defense works. The following factors should be examined:

---The geological structure of the area, that is, how far below the surface to solid rock, the kind of rock and its fissures, the kind of scree covering the rock; soil moisture, and freezing conditions; solifluction, and eventually the chemistry of the soil and its compatibility with the foundation materials.

---The possibility of strengthening the subsurface soil layers. For this purpose the ground testing described in the appendix may be useful.

---Soil conditions. Because structures differ in their foundation requirements, soil conditions should be considered before choosing the type of structure to be used.

---The kinds of footing to be used, that is, prefabricated or made on the spot.

Classes of soil	Glide factor, N	
	Aspect  WNW-N-ENE	Aspect  ENE-S-WNW
Class I ---big boulder (d* ≧ 30 cm). ---terrain with more or less big outcroppings of rocks.	1.2	1.3
Class II ---surface covered with shrubs at least 1 m tall. ---well-expressed mounds covered by grass and tiny shrubs; the mounds must be at least 50 cm high. ---well-pronounced cow trails. ---boulder (d* about 10-30 cm).	1.6	1.8
Class III ---short grass with little shrubs (erica, rhododendron, calluna, alnus, shrub pines under 1 m in height) ---small boulder (d* ≦ 10 cm) intermingled with grass and brush. ---only a few expressed mounds up to 50 cm tall overgrown by grass and little shrubs. ---grass with indistinct cow trails.	2.0	2.4
Class IV ---smooth, long-bladed grass. ---smooth outcropping rock plates with stratification planes parallel to slope. ---smooth scree mixed with earth. ---swampy depressions.	2.6	3.2

d* is the diameter of the blocks that determine the roughness of the soil surface.

II. GENERAL REVIEW OF THE EFFECTS OF SNOW PRESSURE

This section gives only general information about snow forces. The design of the structures is given in Section III.

ART. 26 The snow pressure, in a plane perpendicular to the slope, is generally composed of

---the pressure that results from a local blocking of the creep movement (creep pressure) and of the glide movement which eventually develops (glide pressure)
---the pressure that results from hindering the transverse expansion that would take place under the influence of the component of gravity that is perpendicular to the slope (nivostatic pressure).

A. THE COMPONENT OF SNOW PRESSURE PARALLEL TO THE SLOPE

ART. 27 1. The component of the creep and glide pressure parallel to the slope exerts a force on a unit length of an infinitely long supporting plane erected perpendicular to the slope that is equal to

$$\boxed{S'_N = \gamma_S \cdot \frac{H_S^2}{2} \cdot K \cdot N} \qquad (27)$$

S'_N component of snow pressure parallel to the slope per unit length of the supporting plane

γ_S average density of the snowpack (varies with the altitude and the aspect of the slope)

H_S snow depth measured vertically

K creep factor (a function of the angle of slope ψ and the snow density γ_S , as shown in the table below)

N glide factor (refers to the glide pressure and varies with the roughness of of the ground surface and the aspect of the slope)

Creep factor K as a function of γ_S and ψ

γ_S (kg/m³):	200	300	400	500	600
K/sin 2ψ:	0.70	0.76	0.83	0.92	1.05

To obtain the approximate values of K corresponding to the snow density, the given values K / sin 2ψ are multiplied by the values for sin 2ψ.

2. S'_N is assumed to be evenly distributed throughout the entire depth of snow. Actually this is a simplification since even in a homogeneous snow cover the pressures are distributed in a complicated manner.

3. The nivostatic pressure may generally be neglected in relation to the creep and glide pressures.

B. THE COMPONENT OF SNOW PRESSURE PERPENDICULAR TO THE SLOPE

ART. 28 1. A force component perpendicular to the slope develops when a rigid wall, built perpendicular to the slope, hinders the settlement of snow because of the adhesion of the snow to the rough wall surface. It is expressed as

$$\boxed{S'_Q = S'_N \frac{a}{N \cdot \operatorname{tg} \psi}} \qquad (28,\ 1.)$$

$$\frac{a}{N \cdot \operatorname{tg} \psi} = \operatorname{tg} \varepsilon = \frac{S'_Q}{S'_N} \qquad (28,\ 2.)$$

S'_Q component of snow pressure perpendicular to the slope per unit length of the supporting plane

ε angle between the resultant force and S'_N. The resultant force is designated as the vectorial sum of $S'_N + S'_Q$.

a ratio depending on the kind of snow; this ratio may vary between 0.2 and 0.5.

2. S'_Q is assumed to be distributed equally over the whole height of the structure.

C. ADDITIONAL FORCES IN THE CASE OF AN INCLINED SUPPORTING PLANE

ART. 29 If the supporting plane is not perpendicular to the slope, it is necessary to add the weight, G', to the components S'_N and S'_Q. G' is the weight of the snow prism formed by the supporting plane and its extension to the ground and by a plane perpendicular to the slope at the point, where the extension of the supporting plane intersects the ground.

For a rigid supporting plane, the formula for G' is

$$\boxed{G' = \gamma_S \cdot \frac{D_S^2}{2} \operatorname{tg} \varrho} \qquad (29)$$

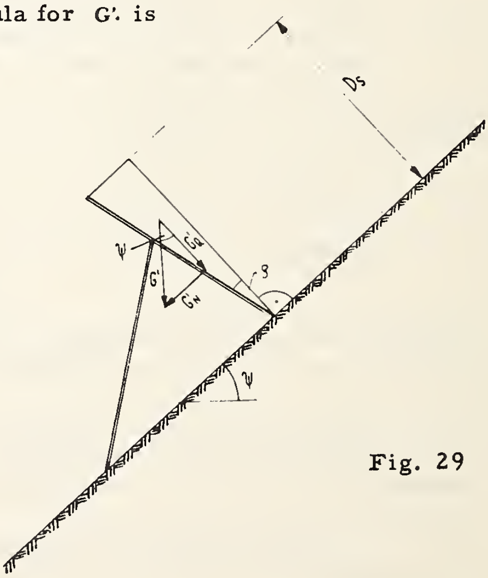


Fig. 29

G' weight of the snow prism per unit length of structure

γ_S average density of the snowpack

D_S thickness of snow cover measured perpendicular to the slope

ϱ angle between the supporting plane and the normal to the slope

G'_N, G'_Q components of G' parallel and normal to the slope, respectively.

D. END EFFECTS

ART. 30 1. If the extension of the supporting plane is limited in length, end-effect forces will be present. These forces are due to the plastic flow of snow masses around the ends of the supporting plane. They depend on all factors influencing the snow pressure on an (theoretically) infinitely long structure. Furthermore, they vary with the size and the roughness of the supporting plane and vary greatly with the gliding of the snow cover.

The fundamental distribution of snow forces acting on a supporting plane is shown in Fig. 30. Instead of the real distribution of end-effect forces, which may be very difficult to determine, we assume a constant force S'_R per running meter applied over the length Δl in order to simplify calculation. For the calculation of S'_R see Art. 52, 5.

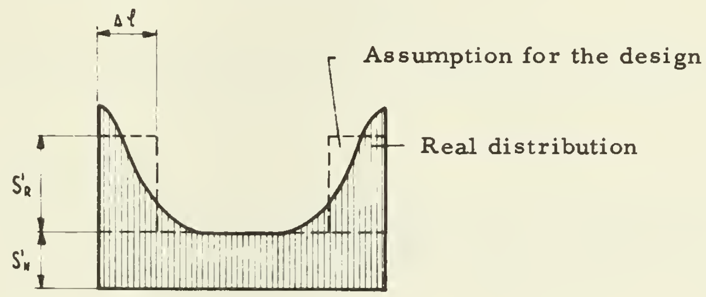


Figure 30. Distribution of the snow pressure on a supporting plane limited in length.

2. The efficiency η of a supporting structure in regard to snow pressures may be defined as the ratio of the effective snow pressure, including the end-effect forces, to the snow pressure without the end-effect forces.

E. RESULTANT FORCE

ART. 31 1. The resultant force can be obtained by a vectorial addition of its components as listed in Art. 27, 28, 29, and 30.

2. For the infinitely long wall, the force is

$$R'_N = S'_N + G'_N \quad (31, 1.)$$

$$R'_Q = S'_Q + G'_Q \quad (31, 2)$$

and

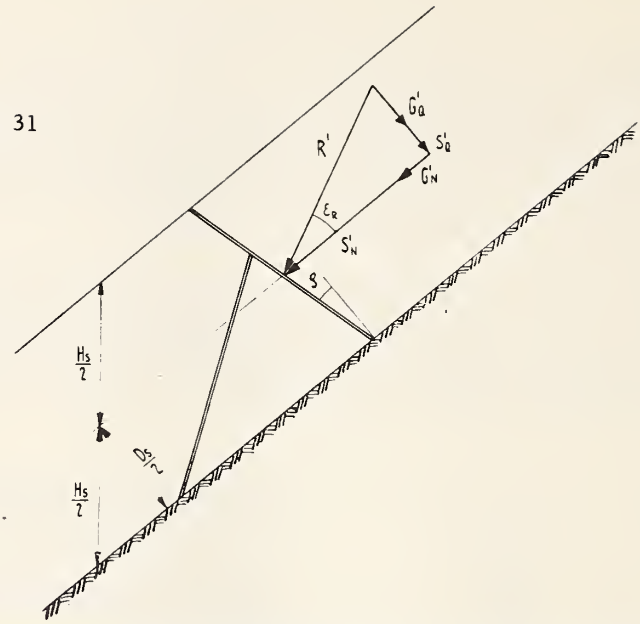
$$\boxed{R' = \sqrt{R'^2_N + R'^2_Q}} \quad (31, 3.)$$

3. Within the length of application of the end-effect forces, the additional force S'_R must be added to the components S'_N and G'_N.

$$R'_N = S'_N + S'_R + G'_N \quad (31, 4.)$$

4. When a regular distribution of the pressure components is assumed, the point of application for the resultant force is at approximately one-half the height of the supporting plane ($H_S/2$, or $D_S/2$)

Fig. 31



5. The direction ε_R of the resultant force which lies in a vertical plane oriented up and down the slope is obtained from

$$\boxed{\operatorname{tg} \varepsilon_R = \frac{R'_Q}{R'_N}} \qquad (31, 5.)$$

It does not have the same value within the length of application of the end-effect forces as in the zone that is free of end effects.

F. SIDE FORCES

ART. 32 Because of uneven terrain and varying snow depths, the resultant force, as seen in a plan view, is not always perpendicular to the supporting plane (see condition in Art. 8). We must, therefore, assume a side load, S_S, acting across the slope (Art. 54,2).

III. GUIDELINES FOR THE DESIGN OF OPEN SUPPORTING STRUCTURES

ART. 33 The following methods of calculation and discussions of permissible stresses refer to open supporting structures with rigid or, with special reservations, flexible supporting planes. These structures are built perpendicular to the slope or tilted downhill at an angle ϱ .

A. STRUCTURAL MATERIALS

a) WOOD

ART. 34 1. When using squared timbers, the classifying instructions of the SIA-Norm No. 163[5] are to be observed. Round timber, including poles, must be sound.

2. The durability of the timbers can be increased by preservatives. The Swiss Snow and Avalanche Institute (Institute SLF) can give more information about protective agents and methods of application based on experimental data.

3. Beech and ash timber must not be used without a suitable treatment such pressure creosoting.

4. Spruce and fir timber have only a limited durability without treatment. They may last 3 to 10 years depending on the conditions where they are used. Therefore, these species should not be used without an effective preservative treatment.

5. The heartwood of such species as larch, pine, oak, and chestnut are more durable. These will usually last about 25 years in avalanche defense areas even in an untreated condition.

b) STEEL

ART. 35 For welded and bolted structures, the following quality specifications must be observed:

1. The steel to be used for the framework should be in qualities 37-3, 42-3, 52-3, as given in DIN 17 100 (October 1957).[5] Other steel qualities are not specified in these guidelines.

2. For the crossbeams, the steel qualities should be 37-2, 37-3, 42-2, 42-3, and 50-2, according to the DIN 17 100 (October 1957).[5] These guidelines do not apply to other steel qualities.

3. For nonwelded (bolted) parts of the grate, the qualities 52-3 and 60-2 as given in DIN Norms 17 100 (October 1957)[5] are also permissible.

c) LIGHT METALS

ART. 36 All aluminum alloys given in DIN Norms 4113 (February 1958) are permitted.

[5] See U. S. equivalents, p. 1.

B. SAFETY FACTORS

ART. 37 1. In discussing safety factors, one should distinguish between foundation, framework, and crossbeams.

2. For the foundation, use a safety factor (against fracture) of two (see also Appendix).

3. The framework must be designed so that its ability to support the applied load will not deteriorate with time, provided the needed maintenance is carried out (Art. 44, 7; 50).

4. Because crossbeams can be easily replaced, slightly higher stresses are permitted for them than for the framework.

C. DIMENSIONS AND PERMISSIBLE STRESSES

a) ELEMENTARY FACTS

ART. 38 1. When nothing else is noted, the pertinent SIA Norms will apply.

2. The following statements are not applicable to auxiliary structures in general civil engineering, such as bridges, and are valid only for supporting structures in the starting zones. They do not apply to diverting and retarding or catchment structures.

3. In contrast to the SIA Norms for the supporting structures, there are no maximum permissible reversible deformations specified.

4. The permanent deformations listed in Art. 45 and 47, and the permissible stresses indicated in Art. 45, were determined with regard to the frequency and duration of snow pressures.

5. For the different types of loading, use the guidelines given in Art. 52-68.

b) WOODEN CONSTRUCTIONS

1. General Remarks

ART. 39 1. The minimum cross section of the construction beams may not be less than the cross section required by computations.

2. If the timber of larch, oak, or chestnut is used, calculations should be based on the cross section of the heartwood unless the sapwood has been treated by a preservative.

2. Framework Construction

Square Timber

ART. 40 1. Square-timber construction is to be designed in accordance with the SIA Norms No. 163 and 164. In spite of Art. 9, paragraph 5 in SIA Norm No. 164, only 70 percent of the permissible stresses must be used due to the special conditions in avalanche defenses.

2. If hardwood is used (chestnut, oak, ash, or beech), the permissible longitudinal stresses (without buckling) and bending stresses may be raised about 25%.

Round Timber and Poles

ART. 41 The permissible stresses given for square timber of class II (Art. 40, 1; 40, 2) may be raised about 25% for longitudinal pressure and bending in round timber and poles. The permissible stresses mentioned in Art. 40-41 can be found in Art. 43.

3. Grate

ART. 42 1. The permissible stresses for the elements of the framework (Art. 40-41) may be increased about 25% for the calculation of the crossbeams of the supporting plane.

2. The stresses mentioned in Art. 40, 1 will be reduced to 80% in the case of a grate. The permissible stresses resulting from Art. 42 are shown in Art. 43.

4. Permissible Stresses for Wooden Construction

ART. 43

Type of loading	Permissible stresses in kg/cm²							
	Framework construction (based on a reduction to 70%)				Supporting plane (based on a reduction to 80%)			
	Square timber, quality conforms with SIA-Norm. No. 163			Round timber including poles	Square timber, quality conforms with SIA Norm. No. 163			Round timber including poles
	I	II	III		I	II	III	
Bending without axial force, maximum boundary stresses σ_R								
Coniferous wood	85	$\boxed{70}$	$\boxed{50}$	$\boxed{90}$	120	$\boxed{100}$	$\boxed{70}$	$\boxed{125}$
Deciduous wood	105	90	65	$\boxed{110}$	150	125	90	$\boxed{155}$
Compression and tension[1] parallel to grain $\sigma_{\parallel}$								
Coniferous wood	70	$\boxed{60}$	$\boxed{{}^{1}40}$	$\boxed{75}$	100	85	[1]60	105
Deciduous wood	90	80	[1]50	$\boxed{95}$	125	105	[1]75	130
Compression perpendicular to the grain $\sigma_{\perp}$								
Coniferous wood								
Loaded area								
flush with end of sill	8				12			
offset from end of sill	11				16			
Deciduous wood								
Loaded area								
flush with end of sill	25				35			
offset from end of sill	35				45			
Shearing parallel to grain τ								
Coniferous wood	$\boxed{7}$				10			
Deciduous wood	$\boxed{9}$				13			

The numbers in blocks are the most important.

[1] Square timber of class III is not permissible for construction members that are loaded predominantly in tension or buckling. If buckling exists, obviously Art. 14 of the SIA-Normals No. 164 must be used.

c) STEEL STRUCTURES

1. General

ART. 44 1. The expression reduced elastic limit σ_{RS} means a strength factor that is computed according to equation 44 from the values for the elastic limit and the elongation at fracture, both of which are obtained from the tensile test:

$$\boxed{\sigma_{RS} = \frac{\sigma_S}{2}\left(1 + \frac{\lambda_5}{30}\right)} \quad [\text{kg/mm}^2] \qquad (44)$$

σ_{RS} reduced elastic limit [kg/mm²]

σ_S elastic limit [kg/mm²]

λ_5 elongation at fracture for a bar whose length is 5 times its diameter[%]

2. The value for λ_5 cannot exceed 30% ($\lambda_5 \leqslant 30\%$).

3. The values of σ_S and λ_5 have to be determined from tensile test on a sample taken from the steel shapes that are used. The test samples have to be taken according to the specifications of DIN 17 100.

4. A special stress analysis must be made for each structure group or for each 200 m of every type of construction material used (i.e., each 200 m of I beams, channel irons, etc.).

5. For the design calculations concerning buckling, tilting, and local buckling, use SIA-Norm No. 161, Art. 18, 19, and 20, structure class II, loading case Z.

6. The values used for the calculation and the real values of the shapes used in the construction have to conform. This should be checked during installation. Structural members must not be used if their safety factor against buckling is less than the factor previously calculated.

7. Add 0.5 mm to the dimensions of the structural members to compensate for loss due to rust. If hot galvanized members are used, no extra allowance is needed for rusting.

2. Permissible Stresses

ART. 45 1. In evaluating the safety factors for buckling, tilting, and local buckling, allowances must be made for a 0.5% permanent deformation of the structural members if the value of 100% is used for σ_{zul}. This is in addition to the provisions of Art. 44, 5.

2. The permissible normal tensile stresses σ_{zul} are:

Framework	Grate
$0.75 \cdot \sigma_{RS}$	$1.00 \cdot \sigma_{RS}$

σ_{RS} means the reduced elastic limit according to Art. 44, 1. Formula 44.

d) LIGHT-METAL STRUCTURES

1. General

ART. 46 The calculations for light-metal structures are to be made according to DIN 4113 (February 1958), loading case HZ. The following extra regulations apply.

2. Supplementary Specifications

ART. 47 1. During the installation of the structures, the dimensions of all structural members must be checked constantly. Use only members that have the same safety factor against buckling used in the original design calculations.

2. A separate stress analysis is necessary for each group of structures or for each 200 m (running length) of every type of structural material used.

3. In evaluating the safety factor for buckling, tilting, and local buckling, in addition to DIN 4113, use the following permanent deformations:

If 100% of σ_{zul} is used, 2% in 30 years

If 80% of σ_{zul} is used, 1% in 30 years

If 60% of σ_{zul} is used, 0.3% in 30 years

e) CONCRETE STRUCTURES

ART. 48 The SIA-Norms give valuable guidelines for the use of concrete, reinforced concrete, and pre-stressed concrete. However, these may be reduced as much as 25% for the design of the supporting plane.

f) WIRE ROPE STRUCTURES

ART. 49 The rough draft of the new specifications on wire ropes issued September 30, 1958, by the Swiss Federal Bureau of Traffic are valuable guides for the design of wire rope structures. However, a safety factor of 2 should be used with the effective breaking strength of wire rope rather than the one given in the above specifications.

D. MAINTENANCE OF THE STRUCTURES

ART. 50 1. The structures must be carefully inspected and maintained at least once a year, if possible.

2. Damage must be repaired promptly.

3. Special attention must be given to wooden structures or wooden parts of structures. Any parts weakened by destructive fungi or insects must be replaced.

E. INCLINATION OF THE SUPPORTING PLANE FROM THE PERPENDICULAR TO THE SLOPE

ART. 51 1. For rigid supporting planes, an inclination downhill of about $\varrho = 15^0$ from the perpendicular to the slope is recommended.

2. For flexible supporting planes, such as nets, it is best to have the line between the foot and the top of the net inclined downhill about 30° from the perpendicular to the slope (ϱ = 30°).

3. On very steep slopes the angle ϱ must be a little smaller than indicated in Art. 51,1 and 51,2.

F. GENERAL TYPES OF LOADING

a) FIRST TYPE OF LOADING

ART. 52 1. The first type of loading is based on an extreme snow depth (see Art. 14,2 and 25,2) equal to the maximum height of the structures but having only a relatively low average snow density of

$$\gamma_H = 0.270 \text{ t/m}^3$$

This density is valid for the reference level of 1,500 meters above sea level and an aspect from WNW-N-ENE. The creep factor, K , is assumed to be 0.74 ($\sin 2\psi = 1.00$)

2. The component of snow pressure parallel to the slope in the zone free of end effects is:

$$\boxed{S'_N = 0.10 \cdot H^2 \cdot N \cdot f_c} \quad [\text{t/m'}] \quad (52, 1.)$$

H Extreme snow depth (measured vertically) at the site of the structure
N Glide factor according to Art. 25,5.
f_c Altitude factor according to Art. 25,6.

3. The snow pressure component perpendicular to the slope is:

$$\boxed{S'_Q = S'_N \cdot \frac{a}{N \cdot \operatorname{tg}\psi}} \quad [\text{t/m'}] \quad (52, 2.)$$

$$\frac{a}{N \cdot \operatorname{tg}\psi} = \operatorname{tg}\varepsilon = \frac{S'_Q}{S'_N} \quad (52, 3.)$$

For the design of each part of the structure (foundations, framework, and cross-beams) choose a = 0.35 or a = 0.50, whichever gives the most unfavorable load for the particular part being considered.

4. The weight of the snow prism for a rigid supporting plane, allowing for a higher snow density near the supporting plane, is:

$$\boxed{G' = 0.150 \cdot D^2 \cdot \operatorname{tg}\varrho} \quad [\text{t/m'}] \quad (52, 4.)$$

D = Extreme thickness of snow cover, in m (measured perpendicular to slope) at structure site ($D = H \cdot \cos\psi$)

5. The end-effect forces S'_R are additional forces (per unit length of the line of structures) that operate parallel to the slope over the length of Δl. No additional end-effect forces perpendicular to the slope are taken into consideration.

$$\boxed{S'_R = f_R \cdot S'_N} \qquad [\text{t/m'}] \qquad (52,\ 5.)$$

with the end-effect factor f_R :

$$\boxed{f_R = (0.92 + 0.65 \cdot N)\ \frac{A}{2} \leqslant (1.00 + 1.25 \cdot N)} \qquad (52,\ 6.)$$

N Glide factor according to Art. 25, 5.
A Interval between structures, in m.

The upper limit of f_R is used for the single structure

$$\boxed{\Delta l = 0.60 \cdot \frac{A}{2} \leqslant \frac{D}{3}} \qquad [\text{m}] \qquad (52,\ 7.)$$

Δl Length in meters over which end effect S'_R is considered to act
D Extreme thickness of snow in m (measured perpendicular to slope)

The upper limit of Δl is used for the single structure.

Fig. 52,1.

End-effect factor according to formula 52,6.

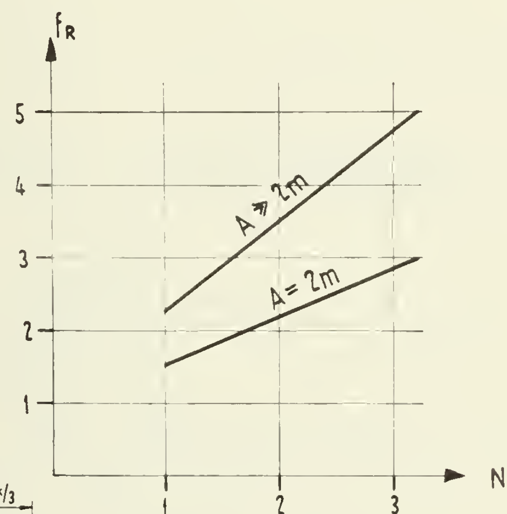
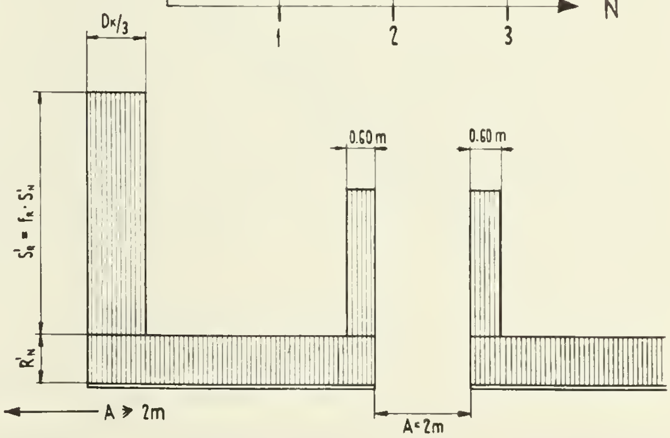


Fig. 52,2.

Distribution of the end-effect forces at a free end of a structure ($D = D_K$) and in the case of an interval A equal to 2 meters.



If laterally neighboring structures are staggered down the slope (in echelon) (according to Art. 23,2), they have the same end-effect forces as nonstaggered structures.

In special cases a symmetrical design of structure based on the higher end-effect force is recommended in spite of the unequal loading of the lateral margins. This design is especially suitable for short structures at the edges of a defense-works area where there is more danger of dynamic loading.

6. The resultant of all the snow pressures is applied at the midpoint of the extreme snow depth H/2.

b) SECOND TYPE OF LOADING

ART. 53 1. This type of loading takes into consideration only a partial covering of the structure by snow but allows for an increased average snow density of

$$\gamma_h = 0.400\ t/m^3$$

based on an elevation of 1,500 m above sea level and an aspect from WNW-N-ENE.

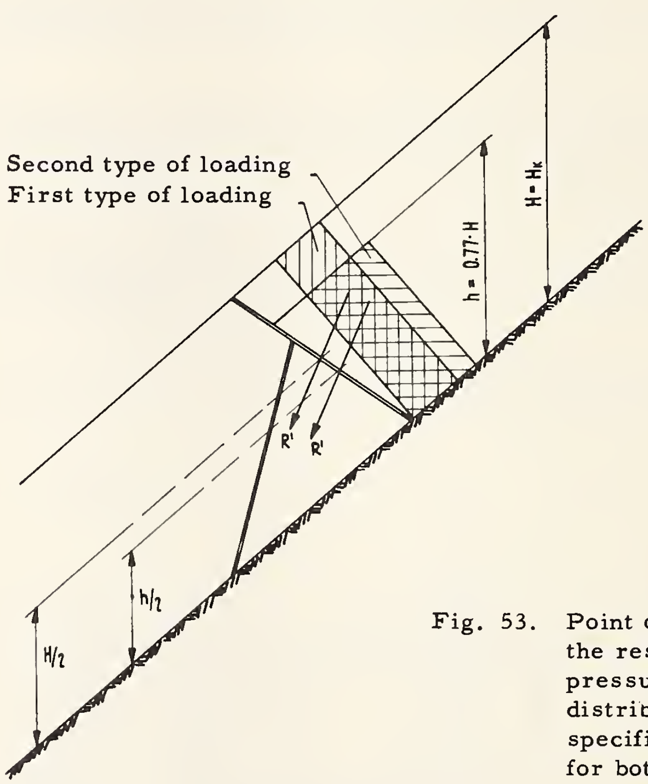


Fig. 53. Point of application of the resultant snow-pressure force and distribution of the specific snow pressure for both types of loading.

2. The second type of loading corresponds to a higher specific snow pressure than the first. The snow depth for the second type of loading is assumed to be

$$\boxed{h = 0{,}77 \cdot H} \quad [m] \quad (53)$$

The snow conditions can be derived from the first type of loading by taking into consideration the settlement of the original snow height, H , plus some extra snow. One should note that $\gamma_h \cdot h > \gamma_H \cdot H$.

3. By means of a little simplification, the same resultant snow pressure, R'; may be assumed for the second type of loading as for the first. The scalar value and the direction are the same. The special features of the second type of loading are

---a lower point of application of the resultant force. In this case at half of h ($h/2 = 0.385 \cdot H$).

---a higher specific snow pressure [t/m²] (Factor 1/0.77 = 1.3).

4. The end-effect factor, f_R , and the length, Δl , of the line of application are considered the same for both types of loading.

c) SUPPLEMENTARY LOADINGS

ART. 54 1. The weight of the structures must be considered wherever it is important.

2. To achieve lateral stability of the structures, a side load, S_S , is assumed to be acting across the slope (see Art. 32). The side load is:

$$\boxed{S_S = 0{,}10 \cdot S'_N \cdot l_o} \quad [t] \quad (54)$$

l_o horizontal distance, span between two neighboring points of support of the same grate, purlin, or net.

The point of application of the side load is assumed to be at one-half the height of the grate or of the net. The distribution of the pressure is uniform. In the case of connected structures (especially continuous structures), the side load may act on any one of the sections in the line of structures. Therefore, the structure must be designed so that (1) each section is capable of withstanding the full side load with no help from adjacent sections, or (2) several sections can be rigidly connected so that the individual sections get enough support from adjacent sections to withstand the side loading. However, at any given time, the load is effective only in one of the sections. Care must be taken that the connection between the grate and the framework is strong enough to transmit the side load.

G. DESIGN OF THE GRATE

a) LOADINGS PERPENDICULAR TO THE GRATE

ART. 55 1. The irregular distribution of the pressure upon the supporting plane means the maximum possible loading must be assumed for the specific loading of its elements.

2. The specific loading resulting from the second type of loading gives the basic loading for the whole height of the supporting plane.

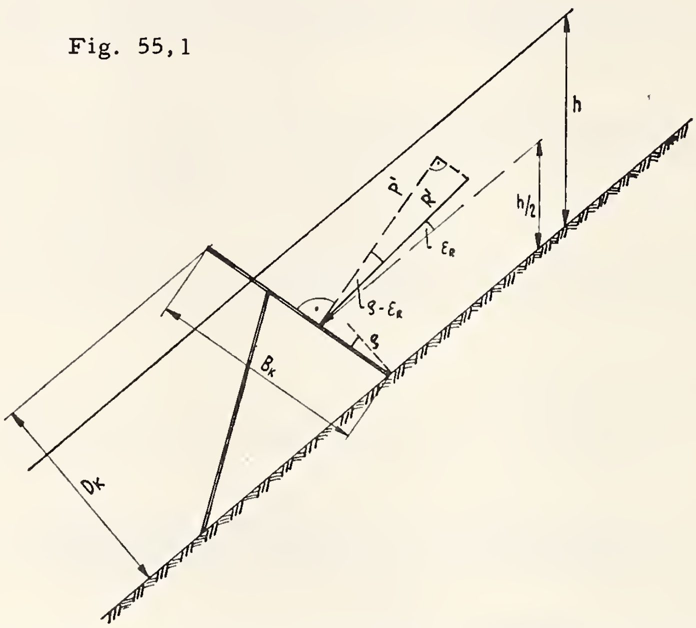
According to Figure 55,1 for a rigid supporting plane

$$P' = R' \cdot \cos(\varrho - \varepsilon_R) \quad [t/m'] \quad (55, 1.)$$

P' Component of R' (Art. 31,2;31,3) perpendicular to the supporting plane

ε_R Angle between R' and a line parallel to the slope; ε_R must be computed according to Art. 31 with a = 0.35

Fig. 55,1



Hence, the specific snow pressure p_h perpendicular to the (rigid) supporting plane is:

$$p_h = \frac{P' \cdot \cos \varrho}{0{,}77 \cdot D_K} = \frac{P'}{0{,}77 \cdot B_K} \quad [t/m^2] \quad (55, 2.)$$

(p_h increases within the length of application of the end-effect forces).

The linear force, acting normal to a bar or rafter having a loading width, b, (b = width of the bar plus a portion of the opening between two bars) is:

$$p_B = p_h \cdot b \quad [t/m'] \quad (55, 3.)$$

3. In addition to the specific loading calculated according to Art. 55,2, there is an extra force working over the whole length of the supporting plane and from the ground up to one-quarter of the height of the supporting plane. This extra force is 25% of the specific snow pressure, p_h , that is acting outside of the influence of the end-effect forces (Fig. 55,2).

4. For supporting planes, where end-effect forces are presupposed (Art. 30, 1), two types of loading are applicable (Fig. 55, 3):

---Loading with end-effect forces S'_R calculated according to Art. 52, 5
---Loading without end-effect forces S'_R .

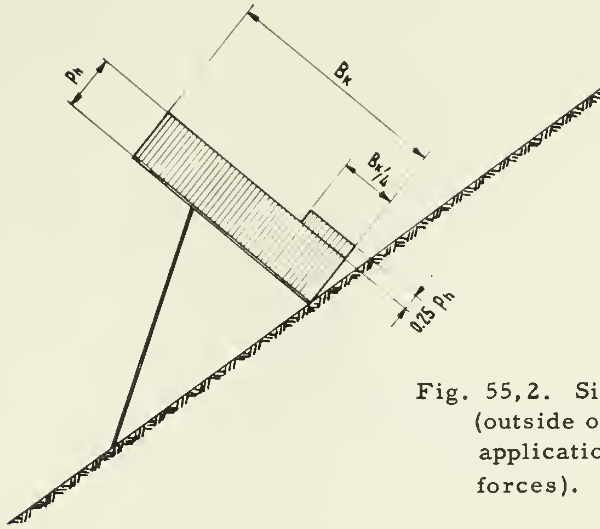
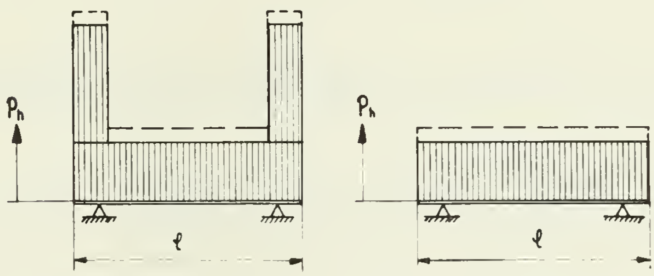


Fig. 55,2. Side view (outside of the length of application of end-effect forces).

Fig. 55,3. Plan view



with end-effect forces without end-effect forces

b) LOADING PARALLEL TO SUPPORTING PLANE AND PERPENDICULAR TO BARS OF A BRIDGE OR PARALLEL TO RAFTERS OF A RAKE

ART. 56 This type of loading (henceforth called transverse loading) comes from the form and size of the supporting plane, that is, from the type of structure. Therefore, it will be dealt with in the specific chapters dealing with the different types of supporting structures.

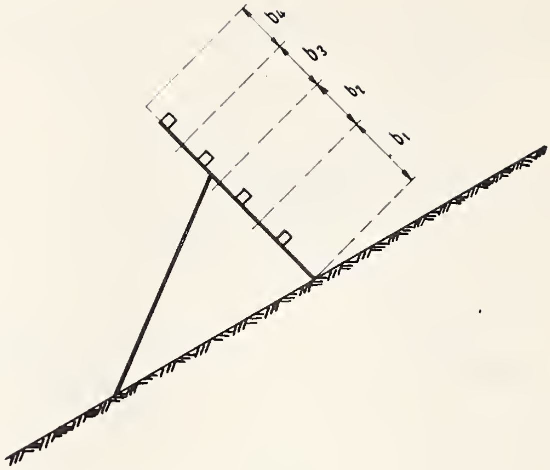
c) SPECIFICATIONS FOR DESIGN OF SUPPORTING PLANE OF SNOW BRIDGES (bars are aligned across the slope)

1. Normal Forces

ART. 57 1. The bars must be designed according to the effective loading width, b, except that the uppermost bar must not be weaker than the neighboring bars.

2. The loading width of the lowest bar reaches to the surface of the ground (Fig. 57,1).

Fig. 57,1



2. Transverse Loading

3. A linear loading, q_B , is assumed for the design of the bars. This linear loading may act downward <u>or</u> upward (Fig. 57,3). According to Fig. 57,2

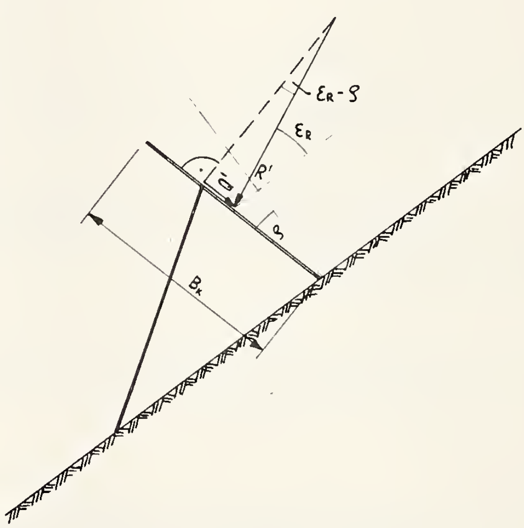
$$Q' = R' \cdot \sin(\varepsilon_R - \varrho) \quad [t/m'] \quad (57, 1.)$$

Q' Component of R' (Art. 31,2) parallel to the supporting plane

ε_R Angle between the direction of R' and a line parallel to the slope.

This angle is calculated according to Art. 31 with a = 0.5.

Fig. 57,2



The uniformly distributed specific transverse loading, q_h , is:

$$q_h = \frac{Q' \cdot \cos\varrho}{0.77 \cdot D_K} = \frac{Q'}{0.77 \cdot B_K} \quad [t/m^2] \quad (57, 2.)$$

The linear transverse loading acting upon a bar is:

$$q_B = q_h \cdot b \quad [t/m'] \quad (57, 3.)$$

4. The minimum value for the transverse loading is considered to be:

$$\boxed{q_B = 0{,}20 \cdot p_B} \qquad [t/m'] \qquad (57, 4.)$$

($p_B = p_h \cdot b$, p_h as defined in Art. 55,2 and 55, 3)

The above minimum value should be used even though in the cases of high glide factors and high slope angles a smaller one could be computed.

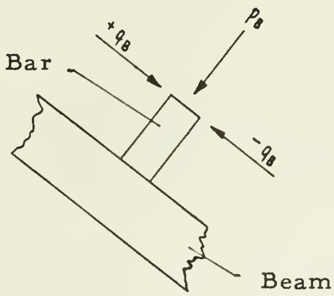


Fig. 57, 3

5. The line of application of the transverse loading q_B is on the outermost, upslope edge of the bar (Fig. 57, 3).

6. The normal loading p_B has to be varied between the maximum possible value and the value of q_B holding q_B itself constant. The structural members must be designed to withstand the stresses under both conditions.

7. Torsion stresses as a result of the transverse loading have to be taken fully into consideration.

8. The width of opening, w, between the single bars and between the lowest bar and the ground must not exceed 30 cm to prevent loose snowslides from flowing through.

9. The uppermost bar has to be firmly attached to withstand possible upward dynamic forces.

10. The effective work height, H_K , in the case of staggered bars in the top row is defined as the arithmetic mean value of the heights of the uppermost bars measured vertically from the ground to the upper edges of the bars.

11. The length of a structure, l , means the average length of the bars.

d) SPECIFICATIONS FOR THE DESIGN OF THE SUPPORTING PLANE OF SNOW RAKES (rafters are inclined about 15° downhill from the perpendicular to the slope)

1. Normal Forces

ART. 58 1. The rafters have to be designed according to the effective loading width, b, except in the case of the end rafters. Loading width of the latter is equal to the distance from its center line to the center line of the adjacent rafter. The rafters on the ends are subject to higher specific snow pressure as a result of the end effect.

2. The lower end of the loading width, b, must extend to the ground.

3. The extra force of 25% in addition to the specific snow pressure described in Art. 55, 3, is not applicable to the rafters of snow rakes. However, refer to Art. 61.

4. The second type of loading has to be taken into consideration for the rafters of a rake.

2. Transverse Loading

5. The most unfavorable cross loading of a rafter in a rake operates as a linear force, q_B, working upon the outermost edge of the rafter in the plane of the grate and in the across-slope direction. In this case, it is a side loading. The value of this force is

$$\boxed{q_B = 0{,}10 \cdot p_B} \quad [t/m'] \quad (58,\ 1.)$$

p_B Maximum normal force acting upon a rafter ($p_B = p_h \cdot b$, p_h as defined in Art. 55, 2 and 58, 1., 2, and 3).

The settling force (the component of R' perpendicular to the slope) has to be considered when attaching the rafters to the purlins.

6. The width of opening, w, between the single rafters must not exceed 35 cm. The gap between the lower end of the rafters and the ground must not exceed 20 cm.

7. The effective work height, H_K, is defined as the vertical distance between the upper ends of the rafters and the ground.

e) SPECIFICATIONS FOR SNOW NETS

(Flexible supporting plane usually made of wire ropes)

ART. 59 1. Reduction of the snow pressure. The reduction of the snow pressure parallel to the slope as a result of the flexibility of the supporting plane is taken into consideration by using a reduction factor f_S. This factor is, in a strict sense, dependent upon many factors such as: the gliding of the snowpack on the ground (f_S increases with N), slack, form, inclination, and mesh width of the nets. As the slack and the mesh width decreases, f_S increases and finally approaches 1.

The component of the snow pressure parallel to the slope will be (Art. 52, 2., slightly modified):

$$\boxed{S'_N = 0{,}10 \cdot f_S \cdot H^2 \cdot N \cdot f_C} \quad [t/m'] \quad (59)$$

f_S Reduction factor for a flexible (slack) supporting plane
H Extreme snow depth at the site of a structure, in m

Estimated value for f_S is approximately 0.8 when medium gliding is considered.

2. Since the stresses in a snow net depend mostly upon the slack of the net, the slack must be controlled after the net is mounted.

3. The component of the snow pressure perpendicular to the slope (Art. 52, 3) is not considered for nets.

4. A snow prism is formed by the plane of the net and by a second plane erected perpendicular to the slope, starting at the base of the net. The weight of this prism, G' (where $\gamma_S = 300\ \mathrm{kg/m^3}$), must be added to the snow pressure.

5. Only the first type of loading (Art. 52 with amendments as given in Art. 59, 1., 3, and 4) has to be taken into account for the design of a net. Art. 55, therefore, is not applicable to nets.

6. The specific snow pressure is considered to be distributed equally over the whole height of the net and to have a direction parallel to the resultant force R'.

7. The width of opening, w, between the mesh ropes must not exceed 25 cm even when loaded. In special cases, when frequent loose snowslides are expected, the size of the openings can be reduced by an overlay of wire nètting.

8. Effective work height, H_K, is defined as the arithmetic average of the highest and the lowest points on the upper margin of the loaded net and the ground.

9. The arithmetic average between the length at the base and the length at the top gives the length of the structure, l, for the trapezoidal nets.

H. DESIGN OF THE FRAMEWORK

a) TYPES OF LOADING

ART. 60 1. The two loading types given in Art. 52, 53, and 54 are used to determine the designs of the framework.

2. The geometrical design of the framework can take many shapes since many factors can be varied in its construction. For example, the following features may vary: length of section (span), angle of attachment of supports, location of support attachment, angle between supporting plane and terrain, etc.

The best solutions depend not only upon the external forces and the inclination of the slope but also upon the foundation. Notice that, in case of a changing slope angle, an approximately constant safety factor for all members of the construction can be obtained if the angles of the triangle formed by the supporting plane, the support, and the ground surface, are kept constant.

b) SPECIFICATIONS FOR SNOW RAKES

ART. 61 For the design of the lower purlin (the horizontal member of the framework near the ground to which the rafters are attached) against normal forces, the second type of loading with the extra force of 25% added to p_h (according to Art. 55, 3) is required.

c) SPECIFICATIONS FOR SNOW NETS

ART. 62 1. The loadings for the net, given in Art. 59, are also applicable to the supports.

2. In designing the swivel posts, both the concentric pressure working along the axis of the post and a transverse loading resulting from the direct contact of the snowpack with the post, must be considered. The latter pressure is relatively small. It may be expressed by means of a regularly distributed linear force, q_S, with a value of

$$\boxed{q_S = 0.10 \cdot \eta \cdot H^2 \cdot N \cdot f_C \cdot \frac{\text{Diameter of post}}{\text{Length of post}}} \quad [\text{t/m'}] \quad (62)$$

η Efficiency; here taken as 1.00
H Extreme vertical snow depth at the structure, in m

Diameter and length of post in m

The direction of q_S is perpendicular to the axis of the post, and directed downhill. Posts with an asymetric cross section should not be free to rotate about their long axis.

The line of application of q_S goes through the center line of the post.

3. If, as a result of circumstances related to construction, an eccentric loading of the post takes place, then the pressure associated with the extreme eccentricity controls the design of the post.

I. FOUNDATIONS

a) TYPES OF FOUNDATION

ART. 63 1. Rigid Supporting Structures (Art. 12, 1)

In general, two separate foundations are used for this type of structure. One is an upper or uphill foundation (beam foundation or ground beam); the other is a lower or downhill foundation (support foundation) (Fig. 63, 1).

In case of very unstable ground, it is advisable to connect the upper and lower foundations by a member called a pressure bar (Fig. 63, 2).

2. Flexible Supporting Structures (Art. 12, 2) and Special Constructions (Fences, Suspension Grates)

Tensile stresses can be absorbed by wire ropes anchored to sound rock.

b) GENERAL STATEMENTS ABOUT THE DESIGN

ART. 64 1. The design of foundations is based on the two types of loading discussed in Art. 52, 53, and 54.

2. The loaded parts of the foundation must be at least 50 cm below the surface of the ground. This distance is measured perpendicular to the slope.

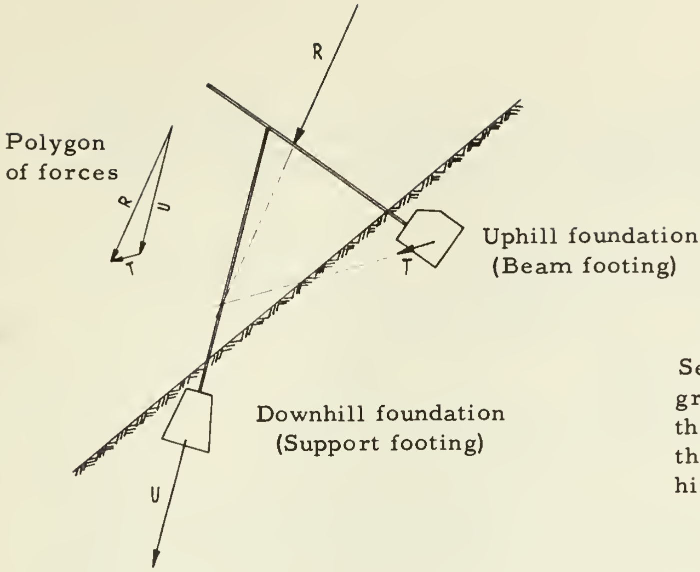


Fig. 63, 1

Separate footings, with graphic determination of the foundation forces in the case of a support with hinged joints on both sides.

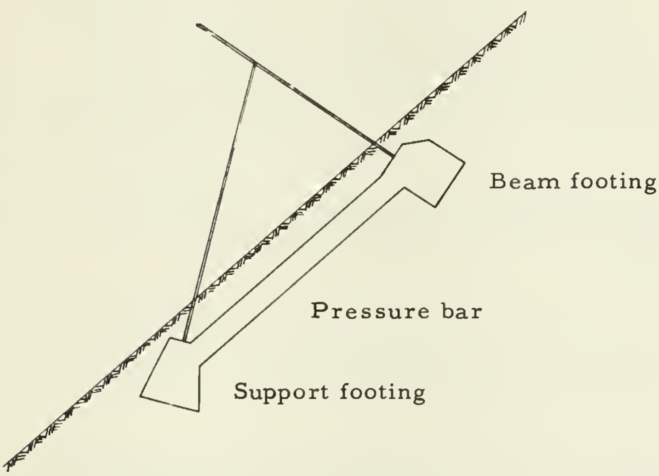
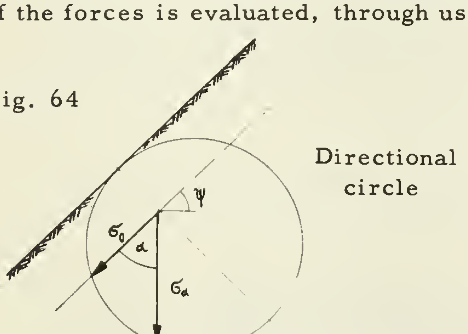


Fig. 63, 2

3. The permissible pressures on soil in the downslope direction should be determined by standard tests (soil-pressure tests); if necessary, ram penetrometer tests can be used.

The relationship between the permissible soil pressures and the direction of the forces is evaluated, through use of the directional circle (Fig. 64).

Fig. 64



The following proportionality factors between the permissible soil pressure parallel to the slope, $\sigma_{o\ zul}$, and the permissible soil pressures $\sigma_{\alpha zul}$ in the direction of the force α (Fig. 64) are applicable. The angle α is the angle between the direction of the force and a line parallel to the slope.

0°	15°	30°	45°	60°	75°	90°
1.00	1.32	1.66	2.0	2.26	2.43	2.50

4. The above relationship is true only for values of α between 0° and 180°, that is, only for soil pressure. If there are tensile forces, the foundations must be designed like foundations of powerline towers. More particulars will be found in the following sections.

c) THE CONNECTION OF THE FRAMEWORK TO THE FOUNDATION IN CASE OF DISINTEGRATED ROCK (LOOSE GROUND)

ART. 65 1. In avalanche defense structures, the framework can be joined to the foundation with either a fixed or a hinged connection.

2. A hinged connection can be used for uphill foundations only when sound rock can be found in an outcropping or near enough to the surface to allow the connection to be securely attached to it. In case of disintegrated rock, a hinged joint gives rise to very unfavorable stresses in the soil with excessive deformations. This, in turn, leads to very expensive foundations. Therefore, in the case of disintegrated rock, a stiff connection between the beam and the foundation block is recommended even though this means an increase in the length of the span because the foundation block can move downhill. Such movement means the stresses in the superstructure cannot be relieved by a firm foundation block.

3. At the downhill foundation, a hinged joint can be used between the support and the foundation without introducing unfavorable soil pressures or uneconomical sizes of the foundations.

4. In using separate foundations (Art. 63,1; Fig. 63,1), a hinged joint is normally used to join the support to the beam (in the framework). However, if a pressure bar is used (Art. 63,1; Fig. 63,2) or if solid rock can be found, a fixed joint can be used between support and beam.

5. When members of the superstructure are embedded in concrete, care must be taken to prevent corrosion. This is especially true for aluminum members. Check with manufacturers for special precautions.

d) LOCAL FOUNDATIONS

ART. 66 A local foundation is one that is fabricated at the place where the structures are installed. An example would be concrete poured into prepared holes.

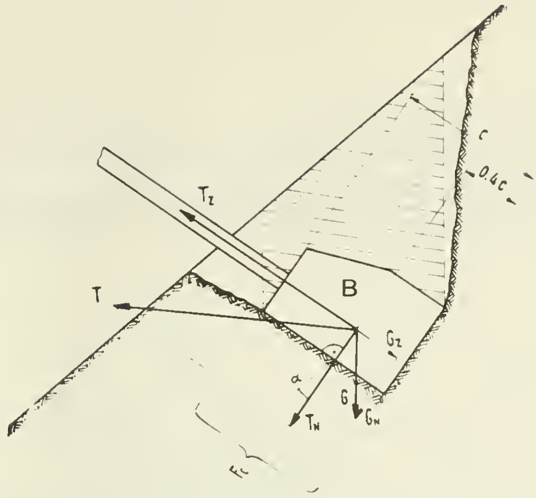
1. Design of the Uphill Foundations Against Soil Pressure Forces

1. Fixed Joints Between the Framework and the Foundation

The foundation is loaded by the single force T. The point of application, B, of the force, T, is considered to be 0.4 c above the base of the foundation block (c is the height of the foundation block).

B corresponds to the lower point of support of the member in question and gives the span. For the design of the beam the contact at B has to be considered free to pivot.

Fig. 66, 1



The downhill face of the foundation, F_c , must satisfy the following conditions:

$$\boxed{F_c \geqslant \frac{T_N + G_N}{\sigma_{\alpha zul}}} \quad [m^2] \qquad (66, 1.)$$

T_N Component of the bearing pressure perpendicular to the block surface F_c

G_N Component of the weight of the foundation, including the soil body shaded in Fig. 66, 1 that is perpendicular to F_c

$\sigma_{\alpha zul}$ Permissible soil stresses in the direction perpendicular to F_c

2. Hinged Joint Between the Framework and the Foundation

The foundation is loaded by a single force T acting eccentrically. The point of application of T is in the joint. According to Art. 65,2, a hinged joint cannot be used in disintegrated rock if the two foundation blocks (upper and lower) are not connected by a pressure bar.

2. Design of the Upper Foundations Against Soil Tensile Forces

3. The tensile force T_Z must satisfy the following conditions (see Art. 54, 1):

$$\boxed{T_Z \leqslant (F_1 + 2F_2) \cdot s_{zul} + G_Z + (T_N + G_N) \cdot \mathrm{tg}\, \varphi_{Ezul}} \quad [t] \quad (66, 2.)$$

F_1 Downhill surface of the foundation hole from the bottom of the hole to the earth surface

F_2 Lateral surface of the foundation from the bottom of the hole to the earth surface (shaded in Fig. 66, 2)

s_{zul} Permissible shear stresses along the surface of the foundation in the undisturbed soil

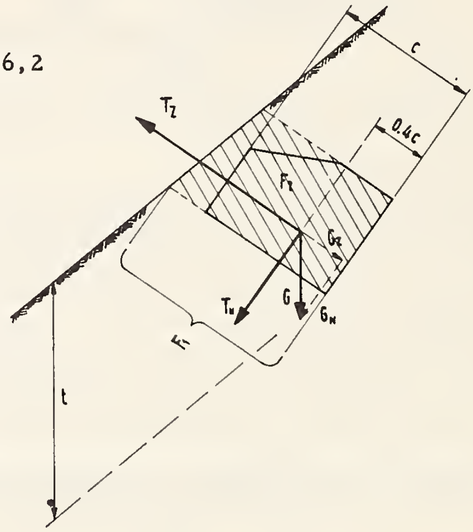
s_B Breaking shear stress along the surface of the foundation in the undisturbed soil

$$\boxed{s_{zul} = {}^1/_2\, s_B} \quad [t/m^2] \quad (66, 3.)$$ (See table below)

G Weight of the foundation including the weight of the soil (shaded)

T_N Component of force T perpendicular to F_1 (under the condition that there is a stiff joint between the framework and the foundation)

Fig. 66,2



φ_{Ezul} Permissible angle of friction in transmitting pressure forces

$$\boxed{tg\, \varphi_{Ezul} = 0.40} \quad (66, 4.)$$

Since no special tests for determining s_B have been done, the following values for s_B . suitable for a total foundation depth of 1 m, can be used:

Kind of soil	s_B [t/m²]
Solid rock	> 80
Poor rock, full of fissures	8.0 -- 80
Preconsolidated soils, moraines	2.0 -- 8.0
Very coarse, condensed gravel	2.0 -- 4.0
Loamy, closely packed, sandy gravel	2.0 -- 2.5
Loose, sandy gravel; sand; and scree	1.5 -- 2.0

The increase in s_B values with an increase in foundation depth, t, can be estimated according to the following table:

Foundation depth t in m, measured vertically	Effective s_B value as a function of the s_B value for 1 m of foundation depth
1.0	$1.0 \cdot S_{B\,(1\,m)}$
1.5	$1.2 \cdot S_{B\,(1\,m)}$
2.0	$1.3 \cdot S_{B\,(1\,m)}$
3.0	$1.4 \cdot S_{B\,(1\,m)}$

A linear interpolation can be used to estimate intermediate values of s_B for depths not given in the table.

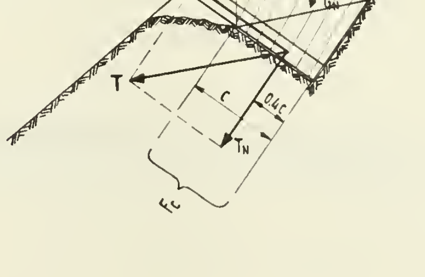
e) PREFABRICATED FOUNDATIONS

ART. 67 Prefabricated foundations are foundations that are manufactured in a factory and are intrenched at the construction site.

1. Design of Uphill Foundations Against Soil Pressure Forces

   1. <u>Stiff Joints Between the Framework and the Foundation:</u> Refer to Art. 66, 1.

Fig. 67, 1



2. For prefabricated foundations that are not undercut, the S_B values given in Art. 66, 3 are not applicable because, when the foundation is pulled out, failure occurs in the backfill whose cohesion is low. The soil must be compacted as much as possible after backfilling the foundation hole. The following calculations presuppose a good consolidation of the fill material.

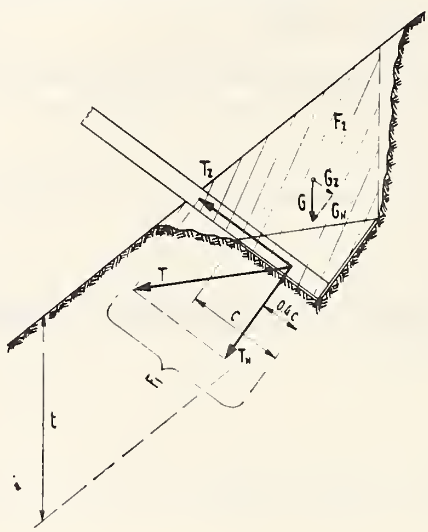
The tensile force T_Z has to satisfy the following conditions (refer also to Art. 54, 1):

$$\boxed{T_Z \leqslant (F_1 + 2F_2)\, s^*_{zul} + G_Z + (T_N + G_N)\, tg\,\varphi_{Ezul}} \quad [t] \quad (67, 1.)$$

F_1 Downhill surface of the foundation from the bottom of the hole to the surface of the earth

F_2 Lateral surface of the foundation from the bottom of the hole to the earth's surface (shaded in Fig. 67, 2).

Fig. 67, 2



s^*_{zul} Permissible shear stresses along the surface of the foundation in disturbed, but consolidated earth material.

For a foundation depth t of 1 m, the following expression applies:

$$\boxed{s^*_{zul\,(1\,m)} = 0.50\ t/m^2} \quad (67, 2.)$$

The increase of s^* with an increase in foundation depth, t, can be estimated from the following formula:

$$\boxed{s^*_{zul}\,(t) = \frac{s^*_{zul\,(1\,m)}}{2}\,(1 + t)} \quad [t/m^2] \quad (67, 3.)$$

G Weight of the (shaded) soil body and of the prefabricated foundation

T_N Component of force T perpendicular to F_1 (under the condition that there is a stiff joint between the framework and the foundation)

φ_{Ezul} Permissible angle of friction in transmitting pressure forces

$$\boxed{\operatorname{tg} \varphi_{Ezul} = 0{,}40} \qquad (67{,}4.)$$

3. Prefabricated foundations normally are very sensitive to corrosion. It might be helpful to test the corrosive nature of the soil.

f) ANCHORAGE IN THE ROCK

ART. 68 The specifications for the design of foundations given in Art. 66 and 67 apply to disintegrated rock and other cases where there is no possibility for additional anchorage in rock.

1. If the foundation is built on sound rock, the following are applicable:

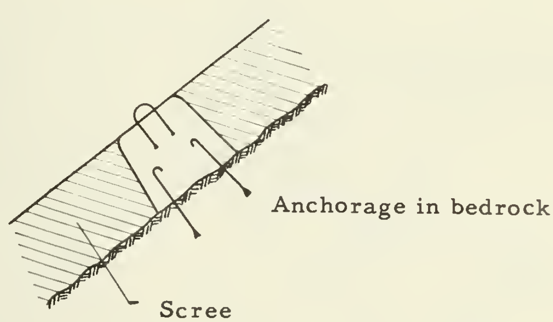
---The tensile forces can be absorbed by means of an anchorage in rock.

---A hinged connection between the framework and the foundation is advantageous. The moment of rotation acting on the foundation can be absorbed by the solid rock.

2. For firm anchorage, the ends of the steel rods placed in the holes should be enlarged or upset by hammering on the end. Care must be taken to use a soft grade of steel that remains malleable even with temperatures as low as -30° C. In important cases steel specialists should be consulted. Open hooks are not permissible because they easily straighten out.

Fig. 68

Foundation in the case of bedrock



3. The use of snow nets depends largely on the possibility of good anchorage in rock. The anchorages are very important and, therefore, must be built with special care. If only one anchorage fails, the whole net may fail.

IV. APPENDIX

A. SOIL PRESSURE TEST

a) GENERAL

For the design of a sufficient and economical foundation it is necessary to know the permissible soil pressures. Art. 64,3, therefore, requires that the permissible values be obtained from standardized soil tests.

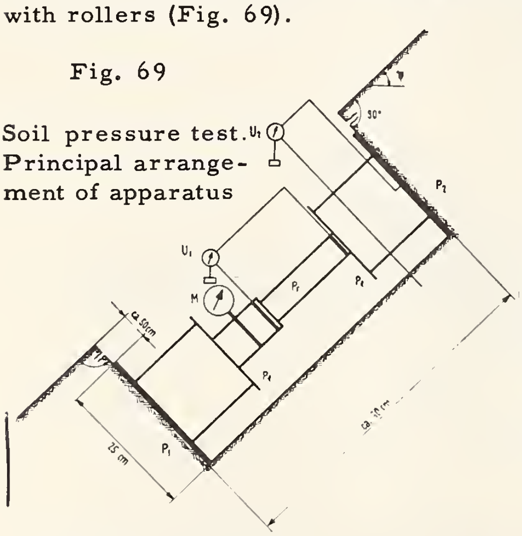
Since the soil pressures (at least in the uphill foundations) act parallel to the slope, a method was developed in which a test load is applied in that direction.

b) DESCRIPTION OF THE TESTING METHOD

The device[6] developed for this purpose consists of a downhill test plate with a surface of 1,000 cm^2, a hydraulic press, and a counter plate with a surface of 1,500 cm^2. Both plates are cut from aluminum shapes used for snow bridges. The hydraulic press is a car jack with a two-scale pressure gage. The outer scale gives the pressure per cm^2 of the test plate, the inner one the force per cm^2 of the piston face. The piston face is 15.6 cm^2 and the maximum force is 8 tons. The force is transmitted over a flat transmitting plate to the webs of the pressure plates. To avoid torsion and/or bending of the piston, the force acting upon the piston is transmitted by means of a ball joint to the transmitting plate. The movement of the test plate is measured indirectly because its center of gravity is not accessible as a result of the arrangement of the transmitting plate and press. Therefore, the piston stroke and the movement of the counter plate are measured. The movement of the test plate is equal to the difference between the movements of the piston and the counter plate. The measurements are made by Huggenberger dial gages with rollers (Fig. 69).

Fig. 69

Soil pressure test. Principal arrangement of apparatus



P_1 = Test plate 1,000 cm^2 (25 cm × 40 cm)
P_2 = Counter plate 1,500 cm^2 (25 cm × 60 cm)
Pl = Transmitting plate
U_1 = Huggenberger dial gage No. 1; measures movement of piston
U_2 = Huggenberger dial gage No. 2; measures movement of the counter plate
δ = Movement of test plate; that is, $U_2 - U_1$
M = Two-scale pressure gage
Pr = Press; piston face is 15.6 cm^2, maximum force is 8 tons
σ_m = Loading of test plate in kg/cm^2
ψ = Angle of slope

[6] Haefeli, R., and Zehnder, M. Fundationen Lawinenverbau 3. Bericht, Fundationskurs 1955, Versuchsanstalt für Wasserbau und Erdbau an der ETH. 28.5.1955. [Foundations for Avalanche Defenses. Rpt. 3. Course for Foundations 1955. Hydraul. and Soil Mech. Res. Sta., Fed. Inst. Tech. (ETH), Zurich, May 28, 1955.]

c) THE TEST AND ITS INTERPRETATION

The test plate must be placed at least 50 cm below the surface as mentioned in Art. 64,2. The length of the test pit, measured across the slope, must be large enough to allow a careful setting and handling of the instruments; that means it must be about 120 cm long. The car jack is placed in the test pit with the piston pointing uphill. After setting the device, the soil is preloaded until the dial gages no longer move and until the test plate fits to the soil surface with the whole face. The needed preload is about 0.25 to 0.50 kg/cm^2. The dial gages are reset to zero. After that the pressure is applied gradually by steps. The steps are, depending on the soil, 0.25 to 0.50 kg/cm^2. The dial gages are checked at the moment when the pressure gage reaches the desired load (time zero). After intervals of 1, 2, 4, 8, and so on, minutes, the movements are recorded under constant pressure until the dial gages no longer move. Then the next pressure step is applied and recorded similarly. This procedure is repeated until the critical deformation of the soil is reached. If circumstances allow, the soil is to be loaded to fracture.

The deformation of the soil under the test plate is plotted against the specific plate pressure (Fig. 70). For these tests, a movement of the test plate of about 2 cm, starting at the moment when the preload is applied, is considered to be the critical deformation of the soil. The specific load $\sigma_{kritisch}$ that corresponds to the critical deformation is obtained from the graph. A safety factor of 1.5 is applied to the critical deformation, free of fracture, to obtain the admissible load $\sigma_{o\ zul}$.

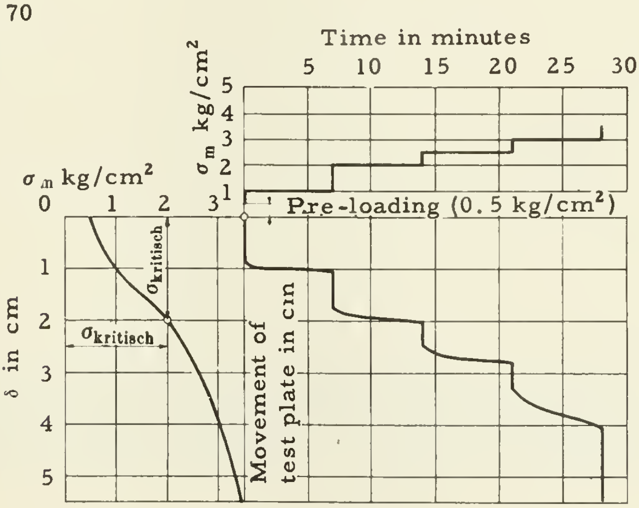
$$\sigma_{o\ zulaessig} = \frac{\sigma_{kritisch\ (2\ cm)}}{1{,}5}$$

If during the test, the soil fractures, then

$$\sigma_{o\ zulaessig} = \frac{\sigma(Bruch)}{2}$$

The lower value of these two figures is considered to be the admissible $\sigma_{o\,zul}$

Fig. 70



B. RAM TEST

The ram test profile that is gathered with a special ram penetrometer [7] is used as a completion to the soil pressure test. Under the assumption of similar soil conditions, there is a correlation between the pressure test and the ram resistance, since the latter is the multiple of the first. [8]

It is possible to locate zones of equal or similar resistance with the ram penetrometer that would save time in carrying out pressure tests. Experience shows that two tests per zone will do. The use of the ram penetrometer may be impossible because of rocks in the soil. In this case test pits will give the necessary information about the soil conditions.

C. FIELD PROCEDURE FOR CARRYING OUT THE SOIL TESTS

After the site of the structure is marked, the location of the foundation is checked with the ram penetrometer. Then zones of similar soil conditions are found. Pressure tests are carried out in two test pits per zone. If the results are comparable, they are considered as representative for the zone. Otherwise, more tests are necessary.

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[7] Haefeli, R., Amberg, G., and von Moos, A.: Eine leichte Rammsonde für geotechnische Untersuchungen. Mitteilung Nr. 21 aus der Versuchsanstalt für Wasserbau und Erdbau an der ETH. [A light ram penetrometer for soil testing. Hydraul. and Soil Mech. Res. Sta., Fed. Inst. Tech. (ETH), Zurich. Res. Note 21.]

[8] Haefeli, R., and Zehnder, M.: Korrelationen zwischen dem spezifischen Rammwiderstand und der zulässigen Bodenpressung in hangparalleler Richtung. Fundationen Lawinenverbau. 6. Bericht. 30.11.1957. [Correlations between the specific ram resistance and the admissible soil pressures parallel to the slope. Foundations of Avalanche Defenses, Rpt. 6. Nov. 30, 1957.]